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# Mock Certification Basis for an Unmanned Rotorcraft for Precision Agricultural Spraying

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November 2015

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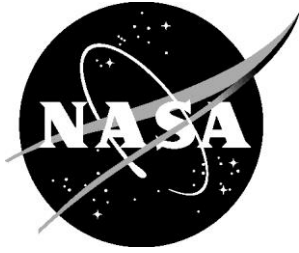
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## Acronyms and Abbreviations

ADS-B	Automatic Dependent Surveillance-Broadcast
AGL	Above Ground Level
ATC	Air Traffic Control
BVLOS	Beyond Visual Line-of-Sight
C2	Command and Control
CFR	Code of Federal Regulations
CMS	Controllability, Maneuverability, and Stability
ConOps	Concept of Operations
CPA	Conventionally-Piloted Aircraft
DPI	Dragonfly Pictures, Inc.
EASA	European Aviation Safety Agency
EPA	Environmental Protection Agency
ESF	Equivalent Safety Findings
FAA	Federal Aviation Administration
FARs	Federal Aviation Regulations
ft	feet
GBDAA	Ground-Based Detection and Avoidance System
GCS	Ground Control Station
GPS	Global Positioning System
HIRF	High Intensity Radiated Fields
IFR	Instrument Flight Rules
JARUS	Joint Authorities for Rulemaking of Unmanned Systems
lb	pound
MOA	Military Operations Area
mph	miles per hour
MSL	Mean Sea Level
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NOTAM	Notice to Airmen
OSHA	Occupational Safety and Health Administration
PPS	Powerplant and Supporting Systems
RLOS	Radio Line-of-Sight
SI	Structural Integrity
SWAP	Size, Weight, and Power
TCAS	Traffic Collision Avoidance System
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System
US	United States
VFR	Visual Flight Rules
VHF	Very High Frequency
VLOS	Visual Line-of-Sight
V <sub>ne</sub>	Never Exceed Speed
WAAS	Wide Area Augmentation System

## Preface

As part of NASA's Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project, NASA is conducting research to investigate airworthiness requirements for UAS performing low-risk commercial operations. The goal of the research is to help fill the void in standards needed to certify UAS to operate routinely and safely in the NAS. Specifically, a case study was conducted to suggest airworthiness requirements for a midsize unmanned rotorcraft performing precision agricultural spraying operations over uninhabited fields. The study considered operations in visual line-of-sight, beyond line-of-sight, and in reduced visibility conditions. This report contains research prototypes of some of the documentation needed to support airworthiness certification, including a proposed (or mock) type certification basis with design and performance criteria for the unmanned rotorcraft, corresponding rationale, a concept of operations, and a hazard list.

This report presents one view of the extent to which existing airworthiness standards for normal category (manned) rotorcraft may apply to a midsize unmanned rotorcraft (i.e., approximately 1000 lb with payload). The mock type certification basis includes requirements on subjects including flight, design and construction, powerplant, equipment, and operating limitations. A complete and expert treatment of all requirements relevant to airworthiness certification of a midsize unmanned rotorcraft, such as those for noise and fuel venting, is beyond the scope of this effort. Prototype certification artifacts were documented using the FAA's issue paper format, so that their form would be familiar to certification specialists and regulatory authorities.

The concept of operations, description of hazards, and mock type certification basis and rationale are intended collectively to provide a plausible picture of the data that influences airworthiness approvals. Because this document covers all of the airworthiness standards for normal category rotorcraft in Part 27 of the Federal Aviation Regulations, the report is substantial. Readers may find some specific sections of this report more relevant to their interests than others. For example, readers interested in using UAS in agricultural pursuits might find the concept of operations (in Section 3) and hazard analysis (in Section 4) most valuable. Regulators and UAS developers may be interested in the mock type certification basis (in Section 5), whereas the rationale for the certification basis (in the Appendix) might be of interest only to regulators. Researchers may find the description of hazards and the concepts for mitigating them (as described in Section 5.1-5.7) most relevant.

As part of the case study, NASA selected a representative UAS platform, namely Dragonfly Pictures' DP-14, to demonstrate the plausibility of the design requirements. NASA evaluated the prototype DP-14 to confirm that an existing UAS could likely (a) accomplish the aerial application mission with equipment based on existing technology and (b) meet the proposed design requirements in the mock certification basis. Ideally, the design requirements in the mock certification basis suggest a reasonable starting point for establishing airworthiness requirements for UAS such as the DP-14 and other aircraft.

The work presented in this report has not been vetted by any regulatory authority. Neither the mock type certification basis nor any other part of the report represents US Government or FAA policy or guidance. Furthermore, this report in no way represents an intent or application for certification on the part of Dragonfly Pictures.



## Executive Summary

This technical report presents the results of a case study using a hazard-based approach to develop preliminary design and performance criteria for an unmanned agricultural rotorcraft requiring airworthiness certification. This case study is one of the first in the public domain to examine design and performance criteria for an unmanned aircraft system (UAS) in tandem with its concept of operations. The case study results are intended to support development of airworthiness standards that could form a minimum safety baseline for midsize unmanned rotorcraft performing precision agricultural spraying operations under beyond visual line-of-sight conditions in a rural environment.

This study investigates the applicability of current methods, processes, and standards for assuring airworthiness of conventionally piloted (manned) aircraft to assuring the airworthiness of UAS. The study started with the development of a detailed concept of operations for precision agricultural spraying with an unmanned rotorcraft (pp. 5-18). The concept of operations in conjunction with a specimen unmanned rotorcraft were used to develop an operational context and a list of relevant hazards (p. 22). Minimum design and performance requirements necessary to mitigate the hazards provide the foundation of a proposed (or mock) type certification basis. A type certification basis specifies the applicable standards an applicant must show compliance with to receive regulatory approval.

A detailed analysis of the current airworthiness regulations for normal-category rotorcraft (14 Code of Federal Regulations, Part 27) was performed. Each Part 27 regulation was evaluated to determine whether it mitigated one of the relevant hazards for the specimen UAS. Those regulations that did were included in the initial core of the type certification basis (pp. 26-31) as written or with some simple modifications. Those regulations that did not mitigate a recognized hazard were excluded from the certification basis. The remaining regulations were applicable in intent, but the text could not be easily tailored. Those regulations were addressed in separate issue papers. Exploiting established regulations avoids the difficult task of generating and interpreting novel requirements, through the use of acceptable, standardized language. The rationale for the disposition of the regulations was assessed and captured (pp. 58-115). The core basis was then augmented by generating additional requirements (pp. 38-47) to mitigate hazards for an unmanned sprayer that are not covered in Part 27.

### Findings and Results:

The research produced some of the initial artifacts that would be developed in a traditional aircraft certification program. Namely, a mock airworthiness certification basis for a midsize (unmanned rotorcraft (approximately 1000 lb with full payload) was derived from an analysis of Part 27, along with the generation of UAS-specific requirements, based on hazards identified through operational and functional hazard assessment. The certification basis also includes seven supplemental issue papers that address new or novel aspects of the unmanned agricultural rotorcraft.

The type certification basis comprises 67 requirements in its core, plus seven additional issue papers. Eleven of these requirements were adopted as written from Part 27's original 260 regulations. A total of 119 regulations from Part 27 were outright excluded. Of the residual 130 regulations, 56 had their text modified for inclusion in the certification basis, while the remaining 74 had their intent abstracted into three special issue papers. These three special issue papers (pp. 32-37) detail high level requirements on the subjects of: (1) controllability, maneuverability and stability, (2) structural integrity, and (3) powerplant and support systems. The issue papers address these topics in a less prescriptive fashion than Part 27. The certification basis also includes four additional issue papers (pp. 38-47) that propose requirements for new and novel technology not covered in Part 27. The requirements address (1) vehicle containment, (2) detection and avoidance of other aircraft, (3) detection and avoidance of ground-based obstacles, and (4) command and control links. Altogether, less than 5% of the Part 27 regulations were deemed applicable verbatim to the derived mock type certification basis, 22% were suitable with textual modifications, and 28% were useful, but required substantial re-interpretation.

These results draw attention to the fact that the application of current airworthiness regulations to UAS is not straightforward, even for UAS operating in low-risk environments. Indeed, current airworthiness regulations may be insufficient to ensure the safety of UAS, due to novel operational concepts and vehicle design types and the unique hazards they pose. Furthermore, many regulations, written as they are today, may not be appropriate because they are not relevant to UAS or present an undue burden to the certification process.

The hazard-based approach employed in this research leads to the recognition that airworthiness requirements for a UAS are inseparable from its concept of operations. Any airworthiness assessment of UAS must address the hazards unique to that UAS's design and concept of operations. The following are major findings in the report:

1. A clearly defined concept of operations is crucial to developing suitable design and performance criteria for airworthiness certification of UAS. The operation and UAS must be considered in tandem in order to derive the relevant hazards to be mitigated.
2. A single regulation may act to mitigate multiple hazards. Any proposed modification of an existing regulation from an established set of airworthiness standards must be assessed carefully with respect to all identified hazards.
3. Protection of public safety (i.e., avoidance of harm to people in other aircraft and people on the ground) is the key driver of airworthiness considerations for UAS. The absence of people aboard an unmanned aircraft means that design criteria for manned aircraft might not be directly relevant to the safety of the UAS. For example, many design criteria for manned aircraft are intended to address the risk of hull loss. But, loss of the hull might not be unsafe in many concepts of UAS operation such as precision agriculture. Consequently, design and performance criteria to ensure that hull loss is extremely improbable might not be suitable for many UAS. This point represents a significant shift in system safety thinking for civil aircraft certification.

This research forms a basis for interpreting the extent to which some established airworthiness certification processes and standards for civil aircraft can be applied to UAS. More specifically, the results and supporting artifacts from the mock type certification exercise can provide:

- awareness to the UAS industry about operational parameters and assumptions that should be specified through a concept of operations document to support development of a type certification basis;
- an example of airworthiness certification artifacts to help inform the UAS industry about civil certification;
- a suitable set of design and performance criteria that could be used by regulators as a starting point for establishing airworthiness criteria for unmanned rotorcraft intended for low-risk operations; and
- a preliminary point of departure for establishing design and performance requirements (at the level of typical airworthiness standards) for new systems and equipment (e.g., a containment system for UAS).

These findings and results are based on the development of a research prototype of a type certification basis for a fixed concept of operations (precision agriculture) and UAS type (midsize rotorcraft). Extensions of this basis to different vehicle types (e.g., fixed wing), concept of operations (e.g., surveillance, delivery, etc.), operational environments (e.g., urban, beyond radio line-of-sight, etc.), and levels of autonomy will greatly enhance the applicability of the work.

# 1. Introduction

Three regulatory actions within the past few years have opened the door in the United States (US) for commercial use of unmanned aircraft systems (UAS): the Federal Aviation Administration (FAA) Modernization and Reform Act of 2012 [1], proposed rulemaking for small unmanned aircraft [2], and launch of the Section 333 exemption process [3]. These regulatory actions are useful for many lightweight UAS that can operate in limited risk settings such as operation within visual line-of-sight (VLOS), under visual flight rules, at low altitudes, and at relatively slow speeds. The Section 333 exemptions officially relieve a UAS operator of the need to comply with airworthiness regulations, pursuant to multiple conditions and operational limitations. UAS with less restrictive operational aspirations, such as operation beyond VLOS (BVLOS), will likely require compliance with design and performance standards for airworthiness to operate for commercial use. Standardized airworthiness criteria for different UAS design types do not exist yet.

As part of the Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project, NASA is conducting research to explore airworthiness requirements for UAS performing low-risk commercial operations. This effort aims to determine the extent to which some existing aircraft certification processes and airworthiness standards are suitable for UAS, and how, if necessary, they may be amended to better fit. This work directly supports the FAA's incremental approach to gaining airworthiness approvals by "developing design standards tailored to a specific UAS application and proposed operating environment" [4]. This work also supports the European Aviation Safety Agency's (EASA's) efforts to regulate UAS in the "specific" category [5]. This research aims to lay groundwork to facilitate development of airworthiness requirements for UAS that would neither qualify under the Section 333 exemption criteria (or the "open" category for EASA) nor have sufficient systems and equipment to comply with current civil aircraft standards (EASA's "certified" category).

At the heart of this research is a case study to put forward a suggested set of design and performance standards for an unmanned agricultural rotorcraft operating in a rural environment. This case study examines a midsize unmanned rotorcraft (i.e., approximately 1000 lb with payload) used to spot-treat crops in a precision agriculture context. Ideally, the concept of spot-treatment or targeted aerial application using unmanned aircraft will have a number of benefits, both economic and environmental. According to a recent National Research Council report [6], the United States lags behind other countries in the commercial use of UAS, particularly in agriculture, despite the large potential market. The Section 333 process enables commercial use of small UAS for agricultural work, especially for aerial surveillance and monitoring. However, routine operation BVLOS with larger UAS would have a significant impact on the growth of the UAS industry.

The research reported here takes a hazard-based approach to establishing safety criteria midsize unmanned rotorcraft. The approach evaluates existing regulation in the Federal Aviation Regulations (FARs) Part 27 for normal category rotorcraft, with the goal of determining the extent to which the existing regulations apply to an unmanned rotorcraft operating in a low-risk context. The approach was influenced by previous work on UAS certification frameworks [7-9]. Evaluation of regulations was influenced by the proposed rules for small UAS [2], regulations for light sport aircraft [10], regulations for commercial space operations [11], and recent FAA presentations on UAS certification [12]. This report focuses attention on some of the initial artifacts developed in a traditional aircraft certification program and how those artifacts may differ when applied to a UAS. The artifacts include a mock type certification basis that proposes design and performance criteria for a specimen unmanned rotorcraft and a concept of operations (ConOps) that defines the objectives for precision agricultural spraying. The report also includes rationale for the derivation of requirements in the mock type certification basis, including evaluation of airworthiness standards for normal category rotorcraft [13] and a modified variant produced by the Joint Authorities for Rulemaking of Unmanned Systems (JARUS) [14].

The objectives for this research were to:

- investigate the possibility of specifying suitable design and performance criteria (streamlined in comparison to current airworthiness standards) as the starting point for establishing airworthiness criteria for a specific combination of UAS and concept of operations,
- examine how UAS unique attributes and features can be described in traditional certification program artifacts,
- propose design and performance requirements (at the level of typical airworthiness standards) for new systems and equipment that are not addressed in existing airworthiness standards (e.g., a geospatial containment system), and
- provide a representative example of certification artifacts to the UAS community.

This report is organized as follows. Section 2 briefly describes the scope and key research concepts, especially relevant to UAS certification. Section 3 introduces the ConOps for aerial application using an unmanned rotorcraft. Section 4 provides an overview of the approach used to determine primary hazards for the specimen unmanned rotorcraft and ConOps. That section discusses how those hazards are used to derive the content of the mock type certification basis. Section 5 contains the mock type certification basis, documented using the form of an FAA G-1, Certification Basis Issue Paper [15]. Additional Issue Papers addressing new and novel aspects of the unmanned rotorcraft are included with the certification basis. Section 6 describes one possible UAS configuration, using Dragonfly Pictures' DP-14 unmanned rotorcraft as a reference model, that might meet the requirements specified in the ConOps and in the mock type certification basis. Conclusions follow in Section 7. Text for the requirements and their rationale in the mock type certification basis are included in the Appendix.

## 2. Scope and Research Questions

Several different certificates or approvals are needed for an aircraft to operate for commercial use in the NAS. Certification of an aircraft's airworthiness, meaning that it conforms to its type design and is in a condition for safe operation, is one such approval. FAR Part 21 describes procedural requirements for issuing these approvals. Three different certificates are relevant to airworthiness certification: a type certificate, a production certificate, and an airworthiness certificate. A type certificate is issued for a particular design of a civil aircraft, engine, or propeller insofar as it complies with applicable airworthiness requirements. A type certification basis identifies applicable regulation paragraphs and subparagraphs, exemptions, equivalent level of safety findings, and special conditions that apply to an aircraft certification program. The quality system used for manufacturing aircraft is addressed through production certification. An airworthiness certificate signifies approval that an aircraft, as built, complies with its type design and is in a condition for safe operation. Type certification applies to all aircraft of the same design, whereas airworthiness certification applies on an airframe-by-airframe basis. The same design and performance standards, however, are the basis for both certificates. This report focuses on what those standards might look like for an unmanned rotorcraft system used for precision aerial application, including the potential for trade-offs between operational limitations and type design requirements for UAS. This report does not consider issues related to production or airworthiness certificates or continuing airworthiness for individual aircraft.

The current design and performance standards for conventionally-piloted aircraft (CPA) are often thought to be the logical starting point for determining airworthiness standards for most UAS. Those requirements represent time-honored best-practices for safe design and lessons learned from incidents and accidents. Existing airworthiness standards for CPA levy requirements on aircraft structure, design and construction, powerplant and supporting systems, electrical systems, etc. to safeguard the aircraft, and hence, safeguard anyone on board. Compliance with those requirements is intended to ensure that hull loss or other aircraft-specific failures that could entail harm to onboard passengers and crew are extremely improbable. They also have a secondary effect of protecting persons and property on the ground. Key questions for UAS are (1) *to what extent do existing airworthiness processes and standards apply, given that protection of onboard passengers and crew is not necessary?* and (2) *to what extent can operational limitations be used to offset airworthiness requirements?* To answer these questions, it is helpful to look at key differences in hazards between CPA and UAS and their operations.

Hull loss is always unacceptable in commercial CPA because those on board are likely to be harmed, regardless of the operational context. In contrast, operational context is a significant factor in determining the safety-related risk<sup>1</sup> posed by a UAS [16]. For example, risk posed by a UAS operating in an urban environment is significantly different from risk posed by the same UAS operating in an uninhabited environment. A number of potential UAS operations exist wherein hull loss presents negligible risk to people, because there are no people on board and because there are no uninvolved people expected in proximity to the operation. Operations in the Arctic or over vast stretches of farmland are obvious examples. Ensuring that hull loss is extremely improbable in those cases is more of an economic issue than a safety concern. This point represents a significant shift in system safety thinking for civil aircraft, and has implications for UAS airworthiness requirements. EASA has proposed an operation-centric framework for regulating UAS to reflect this shift in thinking [5].

The case study of a midsize unmanned rotorcraft used for targeted aerial application examines airworthiness standards in light of an operational context where risk to others is limited, but not eliminated completely. Risk to persons overflown or to other airspace users is minimized in a number of ways in the ConOps, including the following.

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<sup>1</sup> References to risk in this report are specific to safety-related risk, in contrast to other types of risk (e.g., security or economics).

- Operations will be conducted only over farmland in rural, agricultural areas. The operation does not include transit between locations (from an airport to the application site or from one application site to another), but could be adjacent to an aviation activity (e.g., conventional crop dusting).
- Operations will typically be very low-altitude, only a few feet over crop height to minimize dispersal of chemicals. The UA will not be flown above 400 ft.
- Operations will be constrained to a pre-defined containment volume over the application site.

Although these operational characteristics reduce risk, they do not eliminate it. Failure of the systems and equipment on board the UA, in the ground control station, or associated with the command and control (C2) links could pose:

- harm to people in the operational vicinity, primarily crew, e.g., from release of high energy parts from loss of rotor system integrity or explosion;
- harm to people in other aircraft, e.g., from failure to detect and avoid other aircraft, particularly aerial applicators (i.e., crop dusters) that enter the operational area;
- harm to people on the ground, e.g., from failure to detect and avoid people who may inadvertently enter the operational area; or
- harm to people and property beyond the operational area, e.g., from loss of containment (i.e., flight beyond the designated containment volume).

The purpose of airworthiness standards is to provide design and performance criteria to mitigate hazards that could lead to the outcomes above. The operational limitations set forth in the ConOps play an important role in understanding and evaluating hazards and potential mitigations.

### 3. Concept of Operations for Targeted Aerial Application Using a UAS

This concept of operations (ConOps) describes a UAS performing a relatively low-risk operation, namely, targeted aerial application of agricultural chemicals such as fertilizers or pesticides to crops (i.e., crop dusting). The general concept is to have an unmanned rotorcraft apply chemicals to relatively small areas in a field of crops that have been determined to need treatment. This operation is intended to be compatible with precision agriculture: applying the right chemical at the right place at the right time. This ConOps describes the entire operation, primarily from the perspective of the people performing the operation. The information in this ConOps is used to derive information relevant to type certification and could also be used to support operational approvals, pilot training requirements, flight manual, continuing airworthiness, etc.

Within this ConOps, targeted aerial application is considered to be spot treatment of distinct areas of a field of crops, to a level of accuracy of at least 1 meter in either direction [17]. Crop treatment instructions are captured in electronic prescription maps that incorporate information regarding crop health, field conditions, and agricultural inputs needed for treatment [18]. Prescription maps can be based on Landsat or other imaging data, such as data from manned or unmanned aircraft, or may be developed by traditional methods, such as direct inspection of fields. The existence of a prescription map suitable to allow the generation of a flight plan for the UAS is assumed. The yellow areas in Figure 1 give an example of how areas in a field requiring treatment might appear on a prescription map.

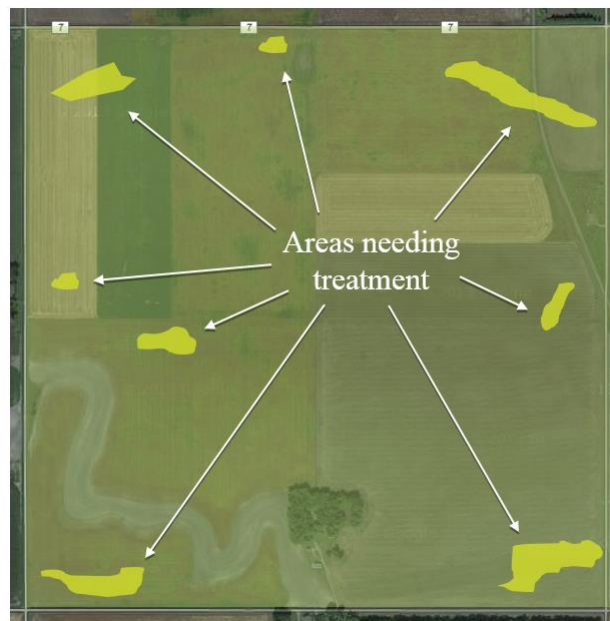


Figure 1. Notional Prescription Map Illustrating Zones Requiring Treatment

An unmanned, midsize rotorcraft was chosen as the target aerial vehicle for this case study. For aerial application, a rotorcraft's ability to operate at very low speeds supports spot treatment of fields. Moreover, a rotorcraft's ability to take off and land without a runway or airport and ability to quickly terminate flight with a minimal landing footprint (compared to a fixed wing aircraft with unknown glide path) are important to constraining the operation of the UAS to a defined location. Having the operation constrained within a well-defined area, in which there is limited possibility of impact with other aircraft or people, is important to limiting operational risk in this ConOps.

The unmanned rotorcraft system includes the UA, ground control station (GCS), sensors, C2 links, and a spraying system. All operations are conducted using this equipment. The rotorcraft and all of its supporting equipment are transported to the application site by ground vehicle(s). The activities associated with the spray operation, including preflight, launch, aerial application, refueling, and replenishment of chemicals, are performed at the application site.

The rotorcraft is remotely operated by a pilot in command<sup>2</sup> from the GCS at the application site. The pilot in command is the person who has final authority and responsibility for the operation and safety of flight of the UA. Additional crewmembers may be needed to assist with tasks such as launch and recovery, refueling, observing air traffic and weather, and monitoring the boundaries.

Operations are conducted by an aerial application service provider (e.g., a crop dusting service) rather than by individual farmers or landowners. The service provider is responsible for meeting operational requirements for handling chemicals, including those required by the Environmental Protection Agency (EPA), as well as training requirements for the pilot in command and crew, and general operating and flight rules that may be levied on UAS, such as those in FAR Parts 61, 91, and 137. Those aspects of the operation are beyond the intended scope of this work, which is to examine type certification considerations.

### **3.1. Operational Objectives and Environment Description**

The following subsections describe the objectives of the spray operation, the environment (geographic, airspace, agricultural, and economic) in which the system is intended to operate, notable safety considerations, and expectations for routine operational use. The operational information is provided here to help identify important safety concerns and key design and operational features that could mitigate those concerns.

#### **3.1.1. Operational Objectives for Targeted Spray Service**

Listed below are the objectives for aerial application using an unmanned rotorcraft for this ConOps. Specific operational activities throughout the phases of operation (from mission planning to landing) are described in Section 3.1.6.

1. The UA should be capable of applying liquid agricultural chemicals (e.g., pesticides, insecticides, fungicides, herbicides, rodenticides, attractants, repellents, and fertilizers) to spots designated on a prescription map of a field. The prescription map could be based on Landsat data or other geospatial information sources.
2. The chemicals should be applied at a level of precision of at least 1 meter in either direction.
3. The UA and supporting equipment should be transportable to the operational area over local roadways.

The nominal operational area is a 0.25 square mile block of farmland (160 acres). This area is known as a *quarter section*. The GCS and supporting equipment are located in such a manner as to provide adequate VLOS and radio line-of-sight (RLOS) for the targeted quarter section and, where feasible, adjacent quarter sections to minimize required movements of vehicles and equipment.

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<sup>2</sup> The pilot in command is responsible for remote operation of the rotorcraft, although direct stick-to-servo control (comparable to a model aircraft) is not required for the UA in this case study.



### 3.1.2. Geography

In this ConOps, the focus is on targeted application of chemicals to crops grown in largely rural areas with significant stretches of farmland. The Red River Valley region of North Dakota and Minnesota serves as a good example of such a region. Corn, wheat, and soybeans are common crops in the region, in addition to specialty crops such as sugar beets. Although many geographic areas would be suitable for this operation, choosing a specific geographic area is helpful in identifying realistic safety and airworthiness considerations.

Farmland in the eastern half of North Dakota including the Red River Valley is generally flat prairie land. The elevation of the Red River Valley region ranges from 780 feet above mean sea level (MSL) in the north to 962 feet MSL in the south.

Farms in the Red River Valley vary in size, with 1,675 acres being an average farm size [19]. Many farms are bordered by “wind breaks” of tall trees, often with creeks, rivers, streams, or ponds sporadically situated within the growing sections. In general terms, land in North Dakota is symmetrically organized by *sections* of land as established by the national Public Land Survey System, each measuring approximately 1 statute mile wide by 1 statute mile long, or 640 acres in total size. Each section is further broken into *quarters*, providing workable *quarter-section* fields of 160 acres each.

There are two significant urban areas in the Red River Valley: Grand Forks and Fargo, ND. Most farms where aerial spraying is conducted are located in rural, sparsely populated areas. Some farms, however, abut housing developments.

North Dakota’s climate is characterized by large temperature variation across all time scales, light to moderate irregular precipitation, plentiful sunshine, low humidity, and nearly continuous wind. The temperature in the growing season (April–September) ranges from about 30° F to 84° F. Average wind speeds during the summer range from 10-13 mph, with up to 20-25 mph gusts.

### 3.1.3. Airspace Environment

The airspace over the Red River Valley to the north of, and including, Fargo, North Dakota is comprised primarily of Class G and Class E airspaces. Points to note relevant to potential airspace hazards include:

- The aeronautical sectional chart indicates the existence of some small obstructions (such as grain elevators), most around 1000-1300 ft MSL.
- There are two National Wildlife Refuges in the region: Ardoch and Kellys Slough. Both are wetlands with significant numbers of birds.
- There is no Special Use Airspace in the region, although there are several Military Operations Areas (MOAs) to the immediate west (Devil’s Lake East/West MOA, Tiger North/South MOA).

Regional airports include Grand Forks International, Grand Forks Air Force Base, and Fargo Hector International, as well as numerous smaller airports. Smaller airports include both towered and non-towered airports, glider fields, crop dusting fields, and private airfields.

### 3.1.4. Agricultural Environment

Precision can be applied to many aspects of farming and crop production, including improved crop assessment through various imaging technologies and improved precision in the application of agricultural chemicals, as shown in Figure 2. When used to modify “aerial application” or “crop dusting,” the word precision indicates that the application need not be to an entire field or at a uniform rate.

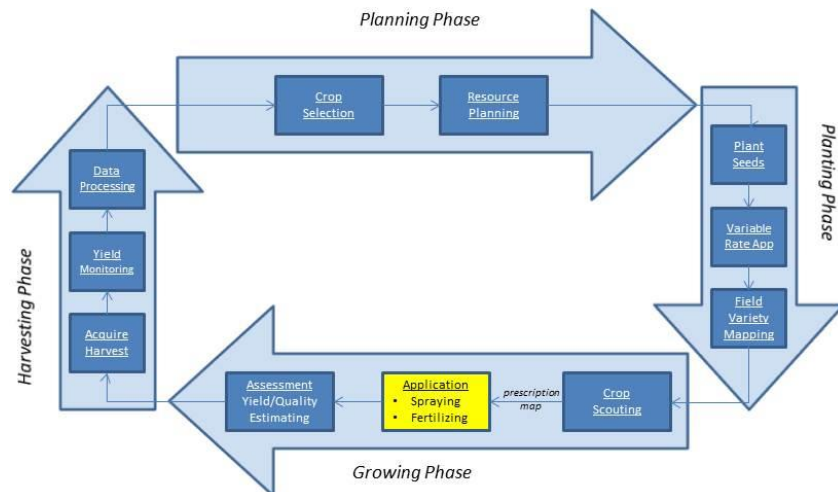


Figure 2. Life Cycle Phases in Precision Agriculture

Improvements in precision can be made with respect to the timing of specific agricultural actions, the geospatial accuracy of actions, and the quantities of agricultural chemicals applied. Although aerial application of chemicals may support several phases of the life cycle, the prominent role is likely in the growing phase.

During the growing phase (summer months), icing conditions rarely occur near ground level. In the rare case when they do occur, there would be no agricultural need to conduct spray operations<sup>3</sup>. Spray operations normally occur during low-wind and low-gust conditions to avoid undesirable drift of chemicals into unintended areas. Therefore, operations are not conducted during thunderstorms or other high wind situations.

### 3.1.5. Economic Environment

Ideally, the concept of targeted aerial application of agricultural chemicals has a number of benefits, including safety, environmental, and economic benefits. Safety benefits include the elimination of risk to the (nonexistent) onboard crew and the reduction of risk to others, arising from the use of smaller, lighter-weight aircraft. Environmental benefits include more effective chemical usage and therefore less chemical runoff. The ability to reduce the overall amount of chemical being dispersed (and thus cost) should lead to quantifiable saving on the part of the agricultural enterprise. Furthermore, there are other benefits, which, while not easily quantifiable, are expected to have a positive impact. Precision aerial application of agricultural chemicals at the right time, in the right place, could increase the value associated with yield per acre by: (1) limiting damage to crops from the infestation being treated, (2) limiting the physical damage to crops during the application process, (3) reducing soil compaction, and (4) providing a more optimal mix of dispersed product through rotor-wash action.

This operation comes with attendant costs, which must then be analyzed in the operational context. Limiting factors on economics of the operational concept include: width of the spray rig, area covered, cost of chemicals applied, fuel, labor etc., and lifecycle costs of the UAS (purchase, operation, and disposal). For economic viability, these costs must be benchmarked with respect to current state of the art application processes, such as conventional aerial application and tractor-based dispersal.

<sup>3</sup> One could conceive of an agricultural spray operation that would be conducted during icing conditions, such as spraying chemicals on fruit trees to prevent damage during a late frost. This usage is not considered in this ConOps.

## *Costs*

Direct costs are expenses that can be directly attributed to the production and harvesting of the crops. These account for 60% of the operating costs. The major direct costs associated with this operational concept of precision spraying are: (1) the cost of chemicals applied, (2) fuel costs (for transport and operation of the UAS) and (3) labor costs of operating the UAS. It is unclear which of these costs will dominate the operational expenses. Chemical costs impact the cost-benefit analysis most directly, as quantifiable savings can be realized through a precise application of less chemical, thereby reducing the amount of chemical applied. These cost savings directly depend on the precision of the delivery mechanism. This will be influenced by the guidance system of the vehicle and by the nozzle delivery system. The cost of the fuel consumed in the course of the precision application of chemicals is directly related to the prescription map, vehicle guidance, navigation and control algorithms and vehicle engine efficiency. Labor costs for the precision application of chemicals under the proposed operational concept are the least clearly defined. Labor costs will be incurred for the setup and take-down operations at the beginning and end of each day. Each individual flight will require pilot and crew time (including, visual observers, if any) to monitor the safe operation of the flight and perform fueling and chemical replenishing operations. Regulatory bodies are developing training and qualification requirements for the pilot and other crewmembers. Costs associated with those activities would constitute indirect labor costs.

### *Key Operational Cost/Benefit Factors*

The average operational time depends on the average flight time, the number of flights to complete the treatment of the quarter section, the time to reload fuel and resupply chemicals, and the time to perform setup and take-down activities.

From an economic standpoint, the average flight time of the system is one of the key parameters of the operational design. Frequent returns for refueling (or chemical resupply) will degrade the operational efficiency of the precision application function. Flight time can be divided into two components: the average time spent applying chemicals (while in flight) and the average time transiting to the area where application needs to occur. The average time in transit is dependent on the prescription map, the initial deployment site of the vehicle, and the path-planning algorithm. The average time spent spraying is dependent on the vehicle's speed in translational lift (moving from hover to forward flight), the vehicle's precision in spraying an area, and the variable rate of spray, as well as the prescription map.

Average chemical coverage is the average volume of chemical required to treat a quarter section. This is determined by the type of chemical, the rate of application, and the prescription map. Average chemical coverage directly influences both cost and timeliness of coverage. The ability to spray a given area with increased precision increases savings based on the amount of chemicals applied.

### **3.1.6. Special Safety Features and Considerations**

There are a few special safety features and considerations worth highlighting for this ConOps that are a consequence of there being no pilot or passengers onboard the aircraft.

#### **3.1.6.1. Containment**

A primary safety consideration is that aerial application will be contained or geospatially bounded. For this ConOps, containment can be thought of in the simplest case as a virtual, 3-dimensional dome or box surrounding the field that constrains the area of operation. In practice, the height of the containment area may be variable so as to limit acceptable altitude near the boundaries. Limiting altitude, especially near the boundaries, can help to protect persons and property outside of the containment area from high energy debris released in the event of rotor system failure or a crash landing.

Procedures prior to and during operation ensure that no people are in the containment zone. The GCS, pilot, and crew are not located within the containment zone but are near the boundaries. The operational area, shown as a dashed red line in Figure 3, encompasses all of the areas targeted for treatment. Takeoff, aerial spraying, and landing all occur within the operational zone. That zone is completely within the containment zone, depicted as the green box in Figure 3. The internal navigation and flight control system for the UAS is intended to limit operations to the operational area defined in the flight plan and limit the spraying to the spray areas (shown in yellow in the figure).

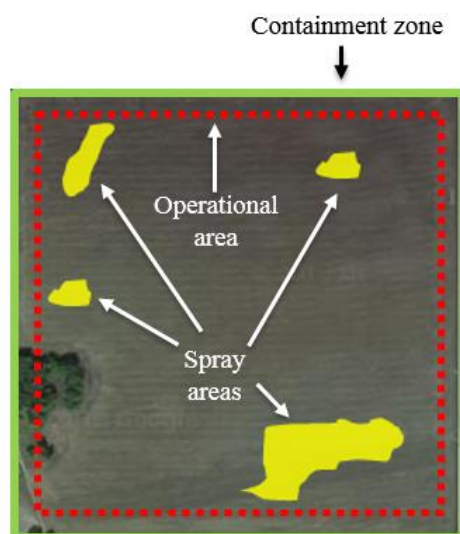


Figure 3. Relationship of Containment Zone, Operational Area, and Spray Areas

This ConOps assumes the UAS has a high-integrity approach to ensure the UA remains within the containment zone. The containment system provides a safety net, intended to limit the exposure of people and property outside of the operational area to UA hazards. The containment function only ensures the UA stays inside the containment zone. The containment function does not prohibit people or vehicles, including other aircraft, from entering the zone. Thus the containment function does not provide air traffic separation (see next subsection). Operating predominately at crop height with a low containment-zone ceiling (400 ft), reduces the chance of an aircraft encounter, but does not eliminate the risk. Ensuring that the UA will not exit the containment zone is a key safety requirement.

### 3.1.6.2. *Detection and Avoidance of Other Aircraft, Weather, and Obstacles*

Without a pilot onboard who can directly observe other aircraft, static or dynamic obstacles, or weather, other means are needed to detect and avoid them. One option is to have ground observers watch the unmanned aircraft and its surroundings. For some scenarios in this ConOps, operations take place in daylight with visibilities of three miles or greater, thus enabling visual line-of-sight (VLOS) operations. VLOS refers to visual observation of UA; that is, operations where visual contact can be reliably maintained with an unmanned aircraft. The FAA currently defines VLOS to be within 0.5 nautical mile of the UA in flight, at a maximum of 400 feet above ground level (AGL) [20]. VLOS operations can use trained observers as the primary means of (1) identifying potential intruder aircraft before they enter the containment zone, (2) recognizing changes in weather conditions that might necessitate a change in the planned activity (e.g., termination or a change in control mode), and (3) identifying obstacles within the containment zone (e.g., farm workers who may inadvertently enter the field or farm equipment that was

not identified in flight planning). Permanent obstacles or other terrain features to be avoided in the operational area can be accounted for in geographical databases or by other means.

Other scenarios in this ConOps include non-VLOS operations, such as operating at night or beyond visual line-of-sight (BVLOS). In those scenarios, ground observers may not be sufficient. Other means of mitigating hazards associated with detecting and avoiding other aircraft, weather, and obstacles are needed. Those means may include, but are not limited to, onboard automation to detect and avoid other aircraft and unanticipated obstacles, or ground-based detection systems, such as those using ground-based radars or acoustics.

### **3.1.6.3. *Hull Loss***

For manned aircraft operations, hull loss (i.e., a crash) is considered a catastrophic event, because of the potential harm to those on board. In this ConOps, crashing within the containment zone, which is monitored to ensure no people are present, is largely an economic concern. Hull loss is only a safety concern in situations where energetic departure of rotorcraft parts or pieces can cause harm to people or property outside of the containment zone (e.g., the pilot or crew). Any spill of agricultural chemicals caused by the loss of the hopper contents in a hull loss scenario may also be a safety concern, but is considered out of scope for this case study.

## **3.1.7. Operational Scenarios**

Operational scenarios describe ways that a system is envisaged to be used through the various phases of operation, which include mission planning, take off, flight, landing, inspection and maintenance. Four operational scenarios are postulated here. The first is a description of daytime operations that occur entirely within VLOS in a rural, agricultural area where there is no aviation activity within three miles. The other scenarios build on the first scenario by introducing additional challenges for the UAS design. For example, the second scenario is similar to the first, except that spray operations are conducted in an area within three miles of known aviation activity (e.g., rural airport, glider port, or aerial applicator field). The next two scenarios add nighttime and low visibility operations that cannot be conducted using current VLOS rules. Each scenario description only addresses considerations that differ from the preceding scenario.

All scenarios assume an airworthy rotorcraft at the outset. All scenarios also assume that adequate planning and reconnaissance of the planned area of operations is performed prior to the operation. Pre-operation activities are assumed to be governed by FAA-approved handbooks approved for the specific commercial activity.

### **3.1.7.1. *Scenario 1 – Daytime Operations Away from other Aviation Activities***

In this scenario, operations take place (a) during daylight hours, (b) in good visibility conditions acceptable for VLOS operations, and (c) at least three miles away from any other aviation activity (e.g., nearby airport or crop dusting operation).

#### ***Mission Planning***

The mission planning phase includes activities that can be done well in advance of the actual spraying task, such as assessment of the physical topography of the fields to be sprayed. Mission planning may include both onsite and offsite work. For example, planning may include preflight reconnaissance of the target fields to identify permanent obstacles, establish “no fly” zones around those obstacles for flight planning, and set containment-zone boundaries. Other activities may include long-range weather checks and set up and checkout of ground-based support systems (e.g., multi-lateration sensors). Mission planning is expected to be done by the service provider’s management personnel or project planners and

schedulers. The number and location of the support personnel is determined by the service provider based on preflight reconnaissance, operational needs, and provisions of the operational approvals given by the FAA and other relevant authorities.

Prior to dispatching the UAS for the spray operation, the service provider obtains the prescription map specifying the locations, densities, and types of chemicals to be applied, and plans the flight paths accordingly.

### *Preflight*

The preflight phase includes day-of-flight activities such as transportation to the field, check out of the rotorcraft (much like a manned aircraft preflight check), checkout of the observer communication system, final weather checks, C2 system checks, and the preflight briefing for all personnel. These activities are done by the crew, which includes the pilot in command, support and maintenance personnel, and possibly observers and an onsite operations manager.

Pre-flight begins with deploying the UA, GCS, datalink, and necessary support equipment to the target area of operations. Once on site, the GCS and support equipment are set up outside of the containment zone, allowing adequate safety margin for the rotors. The UA is positioned within the containment zone, allowing adequate clearance from obstacles above and around the vehicle. Positioning would also consider local ambient wind field and slope restrictions for the UA. The UA is configured and inspected in accordance with specifications in its continuing airworthiness instructions and operations manual. Preflight checks of the UAS, including the spray system, are made per the operations handbook, including checks to ensure continuity of the C2 links, checks for weight and balance, and checks of the physical systems. All necessary flight information, including containment boundaries, location of stationary obstacles, flight plan, and local altimeter information are verified and loaded from the GCS.

The UA is provisioned with fuel and the chemicals to be applied. Safety measures that address the handling and loading of both the fuel and chemicals are specified in FAA-approved operational procedures.

While the UA and GCS are being prepared for flight, support equipment and personnel are deployed. Support equipment may include the transmitters, sensors, and power equipment necessary to support operations. Calibrated positioning sensors might be needed to ensure the prescription map corresponds to the locations the UA flies with respect to ground truth. Personnel include visual observers to monitor for unplanned obstacles, containment boundary violations, and transient low-flying aircraft. The visual observers conduct communications checks with the pilot in command and scan for intruder aircraft and unexpected persons or obstacles in the containment zone.

### *Takeoff and Climb*

When all elements of the system are ready, the pilot in command clears the vehicle for takeoff. The UA is given the command to lift to a hover and does so automatically. Final systems checks are conducted to confirm stability and flight readiness. When checks are complete, the pilot in command clears the aircraft to initiate the preprogrammed navigation path and pressurize the spray system.

### *Flight (Prescriptive navigation and spraying)*

During the flight phase, the UA operates at an altitude consistent with the spraying requirements, typically 10-20 ft above the ground. The UA's navigation system directs the UA to the first spray location avoiding obstacles along the way. For the envisaged operation, the pilot cannot fly the UA via direct stick-to-servo control. Once at the first spray location, chemicals are applied according to the prescription map while the UA maintains an airspeed chosen to control chemical dispersion and reduce fuel consumption. By approaching the spray location from downwind, the ground speed of the UA can be minimized. This helps to control application concentration and reduce overspray. The UA then continues to the other spray locations per the flight plan. The vehicle design and operational procedures include

safety measures to ensure that the spray system cannot inadvertently activate or apply chemicals to locations other than those designated in the prescription map.

Ensuring that the UA stays within the containment zone is a key safety function that the pilot performs with the assistance of the visual observers. The containment function ensures the UA always stays within the containment area. If the UA breaches the operational area (see Section 3.1.6.1), visual observers (or the pilot) will identify this condition and communicate this to the pilot in command, at which time the pilot will take corrective action. The pilot's command, sent via a dedicated link, will activate an independent contingency response system to bring the vehicle down immediately, thus ensuring the UA remains in the containment zone. This action may or may not preserve the integrity of the airframe. Landing on the crops is assumed to be acceptable. Otherwise, a designated safe landing spot may be used.

The C2 link might fail anytime during flight. To address this possibility, the C2 link is continuously monitored. If the link is lost for longer than a defined duration, the independent contingency response system is activated. Other failure events that affect the navigation, guidance, control, or safety systems will also cause the UA to land at its current location (assuming the absence of obstacles). The contingency response system described above may be used at any time to mitigate UA failure conditions, such as loss of positioning data.

Detecting other aircraft that may enter the containment zone is an important safety activity accomplished with the help of visual observers. The observers monitor the local airspace for low-flying aircraft and potential obstacles. When another aircraft that could pose a conflict is detected, that information is communicated to the pilot in command. The pilot in command then sends a command to the UA to execute a preprogrammed avoidance maneuver (e.g., to land or go into a low hover). When the conflicting traffic has passed, a command to resume is sent from the GCS. A ground-based aircraft detection system could also be designed to automatically send a command to the UA. In that case, the pilot would serve as a backup.

Obstacles are avoided during operations in two ways. First, known (static) obstacles are avoided based on "no fly" zones established during mission planning. Unanticipated obstacles within the containment zone are detected by the visual observers or, if available, by an on-board obstacle detection system<sup>4</sup>. It is unlikely that a UAS in a rural environment would need to perform complex obstacle avoidance or return-to-path maneuvers.

Visual observers also watch for changes in the weather. Observers communicate significant changes in weather to the pilot in command, who orders contingency maneuvers if they are warranted.

#### *Descent and Landing*

When the UA has completed the programmed path, reached minimum fuel or payload levels, detected an onboard failure, or is commanded by the pilot, the UA returns to the designated landing spot. Upon arrival, the UA executes an automatic approach and landing to allow refueling and chemical re-supply and any necessary inspection and maintenance.

#### **3.1.7.2. Scenario 2 – Daytime Operations Near an Aviation Activity**

In Scenario 2, daytime operations are conducted within three miles of an airport or aviation activity (e.g., aerial chemical application). In this scenario, the required capabilities and protocols are the same as Scenario 1 except for communication and notification. Communication and notification involve

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<sup>4</sup> It may be possible to implement an on-board obstacle detection system using lidar, radar, infrared cameras, or visible light detectors, or combinations of sensors as permitted by size, weight, and power (SWAP) and cost constraints.

conveying information about the UAS operations to nearby aviators and operators, as well as monitoring communications from those activities.

In this scenario, the airport and any other aviators and operators within three miles are notified of the planned UAS operations. This might be accomplished by filing a Notice to Airmen (NOTAM) or posting a notice at a non-towered airport notifying manned aircraft operators of the dates and times of the planned UAS operations. The preflight briefing for the pilot and visual observers should include information about nearby aviation activities.

During UAS operations, the pilot in command is responsible for monitoring very high frequency (VHF) communications on the appropriate air traffic frequencies, if available. When operations are in progress, the pilot in command maintains a listening watch on the local Unicom or other appropriate frequency and notifies manned aircraft if the UAS breaches the containment zone. If the airport has an operating control tower, the pilot in command monitors the control tower frequency to be responsive to any communications from the tower.

These communications protocols do not substitute for the requirement to detect other aircraft, but do help provide “alerted see and avoid” for other airspace uses and remote crew. The procedures to be followed in the event of a potential conflict with another aircraft are the same as Scenario 1.

### ***3.1.7.3. Scenario 3 – Nighttime Operations***

Aerial spraying operations at nighttime<sup>5</sup> have potential benefits and limitations both from an operational and agricultural perspective. Winds at night are typically lower, which allows easier and more accurate aircraft control and positioning for precise spraying. There is substantially less general aviation traffic at night and the potential exposure to other low-level aircraft is minimal because of restrictions on nighttime aerial work for manned aerial applicators. On the agriculture side, some crops are more amenable to the application of certain chemicals at night.

However, it is harder to see aircraft (traditionally piloted or otherwise) at night. The use of strobes on the UA can increase the likelihood that other aircraft will see it and that it will be seen by its pilot and observers. Noise restrictions may present a challenge for nighttime operations. Detecting ground-based obstacles is more difficult at night. Increased emphasis on strategic measures (e.g., mapping of obstacles) would be needed to maintain safe separation.

Scenario 3 involves nighttime operations that may or may not occur near an aviation activity. In this ConOps, night operations differ from day operations primarily in three ways. Because the pilot and observers may fail at nighttime to notice (1) whether the UA remains in its containment area, (2) whether other aircraft have entered the area, and (3) the presence of obstacles on the ground, there must be an automated means to mitigate these hazards. The contingency response is largely the same as Scenario 1 except that the contingency action could be initiated by automation in addition to pilot action. Due to the significant safety role of the containment function, all parts of this system, including location sensors, must operate with high integrity. If the pilot determines that the UA violates the operational area without triggering the containment system, the pilot has the means to bring the aircraft down through the contingency action. In this case, all operations cease until the cause of failure of the automated containment function is determined.

Using visual observers to detect other aircraft at night is not generally applicable to this scenario. Nighttime operations require an additional approach to detecting other aircraft. A low-cost, automated detect and avoid system is not currently available for the civil UAS market, though one could be developed using existing technology. It is possible to imagine a Ground-Based Detect-and-Avoid System

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<sup>5</sup> Night, per FAR Part §1.1, means the time between the end of evening civil twilight and the beginning of morning civil twilight, as published in the Air Almanac, converted to local time.



(GBDAA) that is a small, portable, and radar-based. The GBDAA system could operate continuously during flight operations and provide the pilot in command with a distinctive warning if an intruder aircraft is detected within a predetermined range of the operation. Given a warning from the GBDAA system, the pilot in command would activate the independent contingency response system (e.g., land immediately or hover), just as he or she would when warned by a visual observer. Once the intruder has passed, the UA would be permitted to resume normal operations.

Finally, day and night operations also differ with respect to active obstacle detection on the ground. Ground intruders (e.g., livestock or people) become difficult to detect at nighttime; even if they also become less likely. Obstacles such as mobile irrigation systems that might not have appeared on original maps of the field are also more difficult to detect at nighttime. For night operations, an approach other than visual observers is needed to detect unexpected obstacles in the field. If that approach uses an on-board detection system, the sensor for the system must be shown to be capable of detecting obstacles at night. Any ambient light requirements for the sensor to operate should be specified in the operations manual as operational limitations.

There are other, more minor, differences between day and night operations. The UA must be equipped with position and anticollision lights to permit visual confirmation of UA position and orientation. Lighting is also needed on the ground to support refueling, reloading, and inspecting the UA.

#### 3.1.7.4. Scenario 4 – Operations Beyond Visual Line-of-sight

Scenario 4 is for operations beyond visual line-of-sight (BVLOS), but within radio line-of-sight (RLOS) that may or may not be near an aviation activity. BVLOS operations include those where visual contact cannot be reliably maintained with an unmanned aircraft due to distance, obstructions, or atmospheric conditions. Early morning fog or low lying clouds are examples of low visibility conditions relevant to aerial spraying operations. There are some advantages to operating in degraded visual conditions. For example, it is unlikely that other aircraft will be operating at low altitudes under visual flight rules (VFR). Required capabilities (for detecting and avoiding other aircraft and obstacles and remaining within the containment volume) remain the same as in the other scenarios, except the means to provide those capabilities cannot rely solely on human vision.

VFR minima for conventionally-piloted rotorcraft per 14 CFR §91.115, shown in Table 1, differ depending on whether operations are conducted in Class D, E or G airspace.

Table 1. VFR Weather Minima for Rotorcraft

Airspace			Flight Visibility	Distance from Clouds
Class A			None	None
Class B			3 statute miles	Clear of clouds
Class C			3 statute miles	500 feet below 1,000 feet above 2000 feet horizontal
Class D			3 statute miles	
Class E	less than 10,000 MSL		3 statute miles	1,000 feet below and above 1 statute mile horizontal
	at or above 10,000 MSL		5 statute miles	
Class G	1,200 feet or less AGL	Day	.5 statute mile	Clear of clouds
		Night	1 statute mile	500 feet below 1,000 feet above 2000 feet horizontal
	more than 1,200 AGL but less than 10,000 MSL	Day	1 statute mile	
		Night	3 statute miles	
	more than 1,200 AGL and at or above 10,000 MSL		5 statute miles	1,000 feet below and above 1 statute mile horizontal

Agricultural operations will presumably take place in Class G airspace, where air traffic control does not provide clearance from other aircraft, but VFR minimums are known by pilots. VLOS operations covering quarter sections would require less than one mile visibility. In theory, VLOS operations could be conducted in Class G airspace with one mile visibility and clear of clouds except for the requirement to detect other aircraft at a range sufficient for the UA to conduct an avoidance maneuver. Procedures for operations with visibility below one statute mile are virtually the same as night operations: a means to detect other aircraft (such as a GBDAA system) will be needed.

The active obstacle detection system should be shown to operate successfully in restricted visibilities if observers cannot see the boundaries of the operational area. Low visibility operations might also necessitate some means to establish when visibility is above or below approved minima.

## **3.2. Operational and Airworthiness-Related Observations Regarding ConOps**

Design parameters and level of automation needed for UAS are strongly influenced by operational, environmental, and economic considerations. The subsections below describe how these considerations for aerial application may impact the design for an unmanned agricultural sprayer. This information provides background data for some of the assumptions underlying the type certification basis.

### **3.2.1. Operational and Environmental Influence on UAS Design Variables**

#### **3.2.1.1. *Tank Volumes (Fuel and Chemical Capacity)***

The fuel and chemical tanks affect the weight, balance, and endurance of the UA, as well as the potential energy available to cause damage in case of an accident. The tanks' contents are part of the vehicle's payload and are subject to weight limits.

Different fields will have different transit and spray requirements, depending on the size and condition of the field. Ideally, the design of the fuel and chemical tanks would allow for variable fuel and chemical loadings. An optimal design for the tanks would minimize the number of refueling and resupply operations for the targeted fields, while having minimal effect on balance as the fuel and chemical tanks are depleted. Ideally, the fuel remaining would be just sufficient to return the UA to the ground transport vehicle with appropriate reserves.

#### **3.2.1.2. *Guidance and Navigation***

The precision with which the chemicals will be applied is a critical factor in the UAS design. Precision aerial application will likely require greater navigation accuracy and control than that needed to meet safety requirements (e.g., to stay clear of obstacles and boundaries). The guidance, navigation and control systems must have sufficient accuracy to navigate to and spray targets with the precision required to achieve cost savings and avoid (over-) spraying unnecessary areas. Inasmuch as the guidance and navigation equipment does not affect safety requirements or constraints, its accuracy and reliability impacts only the profitability of the operation (e.g., through repair, lost operational time, wasted chemicals, or damaged crops).

#### **3.2.1.3. *Visual Observers and Electronic Surveillance***

Tradeoffs exist between using visual observers in VLOS conditions and relying upon electronic surveillance equipment to ensure that the UA remains in its containment zone and clear of ground obstacles and other aircraft. Because the cost of certifying electronic surveillance systems might be substantial, the cost to use visual observers (including training costs) might be less burdensome in the short term. The cost of employing visual observers will depend on the number needed, duties assigned, and the level of training required. If the quality of surveillance provided by visual observers and certified

electronic equipment is equivalent, a straightforward cost-benefit analysis can be made between the two. The analysis should take into account that electronic surveillance will enable aerial application at nighttime, in inclement weather, and at beyond VLOS maximums (Scenarios 3 and 4). Operating under these conditions may provide significant benefits, especially in terms of timeliness of application, and overall increased yield.

### 3.2.2. Business Models

The business model impacts UAS design parameters, especially regarding the degree to which the design needs to accommodate operators and maintenance personnel at a variety of training and skill levels. This ConOps assumes a service-provider model, but an owner-operated model could also be considered. The benefit to the farmer of the service provider model is that the farmer does not need to invest the time and capital upfront and, perhaps more importantly, does not need to employ skilled workers to operate the aerial spray equipment. The advantages of owning the equipment are the elimination of the operator's profit as a cost and (perhaps more importantly) the ability to deploy the equipment on the farmer's own schedule.

### 3.2.3. Summary of Scenario Differences

Some scenarios in the ConOps will require automated equipment that is not necessary in other scenarios. Visual conditions and proximity to other aviation activities affect the level of automation required for the UAS. In the VLOS conditions in Scenarios 1 and 2, visual observers may be sufficient for ensuring containment and detecting intruder aircraft or ground-based obstacles within the containment zone. The limited visibility conditions in Scenarios 3 and 4 (nighttime and low visibility conditions) will require automated systems to ensure that the UA stays within its containment zone, to detect intruder aircraft, and to detect unanticipated ground-based obstacles. Scenarios 2, 3, and 4 assume the need for an aviation radio to communicate with aviators and operators external to the spraying operation. Table 1 summarizes differences among the four scenarios.

Table 1. Primary Differences in Approach to Meeting Functional Capabilities

Functional Capability	Scenario 1 Daytime Operations Away from other Aviation Activities	Scenario 2 Daytime Operations Near an Aviation Activity	Scenario 3 Nighttime Operations	Scenario 4 Operations Beyond Visual Line-of-sight
Ensuring containment	Visual observers	Visual observers	Automated containment system	Automated containment system
Detecting intruder aircraft	Visual observers	Visual observers	Automated detection system (e.g., GBDAA)	Automated detection system (e.g., GBDAA)
Detecting ground-based obstacles	Visual observers	Visual observers	Automated detection system (e.g., ground- based obstacle detection system)	Automated detection system (e.g., ground- based obstacle detection system)
External communication (e.g., with local airport)	N/A	Aviation Radio	Aviation Radio	Aviation Radio

### 3.2.4. Assumptions Regarding the UAS and Precision Aerial Application Service

Understanding the assumptions underlying the operation of a UAS is necessary to properly identify potential hazards and requirements necessary to mitigate them. Listed below are the key assumptions about the aerial application operation and the unmanned rotorcraft for this ConOps. These assumptions

are derived directly from the information in Section 3.1 and represent key airworthiness-related requirements.

1. The UA will have no people on board.
2. The UA will be capable of safe takeoff, flight and landing in the designated operational environment, including the ability to operate in the relevant elevations, winds, wind gusts, and temperatures. Operations will not be conducted during high winds, thunderstorms, or icing conditions.
3. Operations will be conducted in rural, agricultural areas. However, these areas might be near some human presence (e.g., farmhouse or field in which people are working) or other aviation activities.
4. Chemicals will be applied only to designated areas within the field. The probability of unintended application of chemicals on any other agricultural field, or stream, roadway, or populated parcel of land will be minimized.
5. The UA will be a rotorcraft with weight and operating characteristics that would preclude operation under forthcoming FAA small UAS rules [2].
6. The UA will have only one pilot in command and the pilot in command will only be responsible for one UA during a flight. The pilot is required to participate in the management of the flight using the GCS. Autonomous operations, defined here as where pilot intervention is not allowed in the management of the flight [21], are not permitted.
7. The UA will navigate automatically to the areas designated for spot treatment. The UA will follow a flight plan based on the prescription map. Direct stick-to-servo control (comparable to a model aircraft) is *not* required in any mode of operation (e.g., nominal, emergency, etc.).
8. The UA will typically operate a few feet over the crops. Maximum altitude is set at 400 feet above ground level, sufficient to avoid ground-based obstacles (e.g., stand of trees).
9. The UA will operate *only* within a predefined, bounded area or containment zone over the fields to be sprayed. The UA will not be required or permitted to operate at airports or in corridors between a base location and the application area.
10. The containment zone will be cleared of people prior to operation and monitored to ensure that no one enters during the operation.
11. The UA crashing (commonly referred to as hull loss) within the containment zone is not considered a safety concern except in instances where energetic departure of any parts, pieces, or chemicals could harm people or property outside of the containment zone.
12. Operations will be conducted initially in daylight with good visibility conditions. With increasing experience and maturation of the activity and appropriate equipment, operations may be extended to night and in limited visibility conditions.
13. Operations will be conducted only within RLOS. The edges of the containment zone must be within RLOS of the GCS.
14. A means of detecting and avoiding other aircraft, permanent obstacles (e.g., silos or sheds), and other obstacles, animals or persons on the ground (e.g., livestock and farm equipment) in all operational conditions will be needed.
15. Communication and notification about the aerial application operation will be provided as needed when operations are conducted in the vicinity of an aeronautical activity (e.g., glider port, aerial applicator field, etc.).
16. Operations will not occur in Class A. Operations will not occur in Class B or C airspace, without an airspace specific approval.

## 4. Approach

Airworthiness standards for new or novel CPA (e.g., a tilt-rotor aircraft) are typically derived from applicable parts of existing standards (e.g., FAR Parts 23, 25, 27, 29, and 33) with any additional requirements for unique features crafted as special conditions. The standards focus on the aircraft systems and equipment, with minimal consideration of the operational context. Operational limitations, if any, are typically associated with operational conditions such as icing and oceanic operations. For a UAS, however, considering the concept of operations (ConOps) and associated operational limitations was unavoidable from the start. The operational context strongly influences the severity of the consequence of failure of the UAS, especially for short range operations such as those associated with agriculture.

There were three major tasks involved in investigating airworthiness requirements for the specimen unmanned aerial applicator, following the development of the ConOps. Figure 4 shows those tasks, the products produced by each, and how these products relate to the content of the mock type certification basis. Each task is explained in the following subsections.

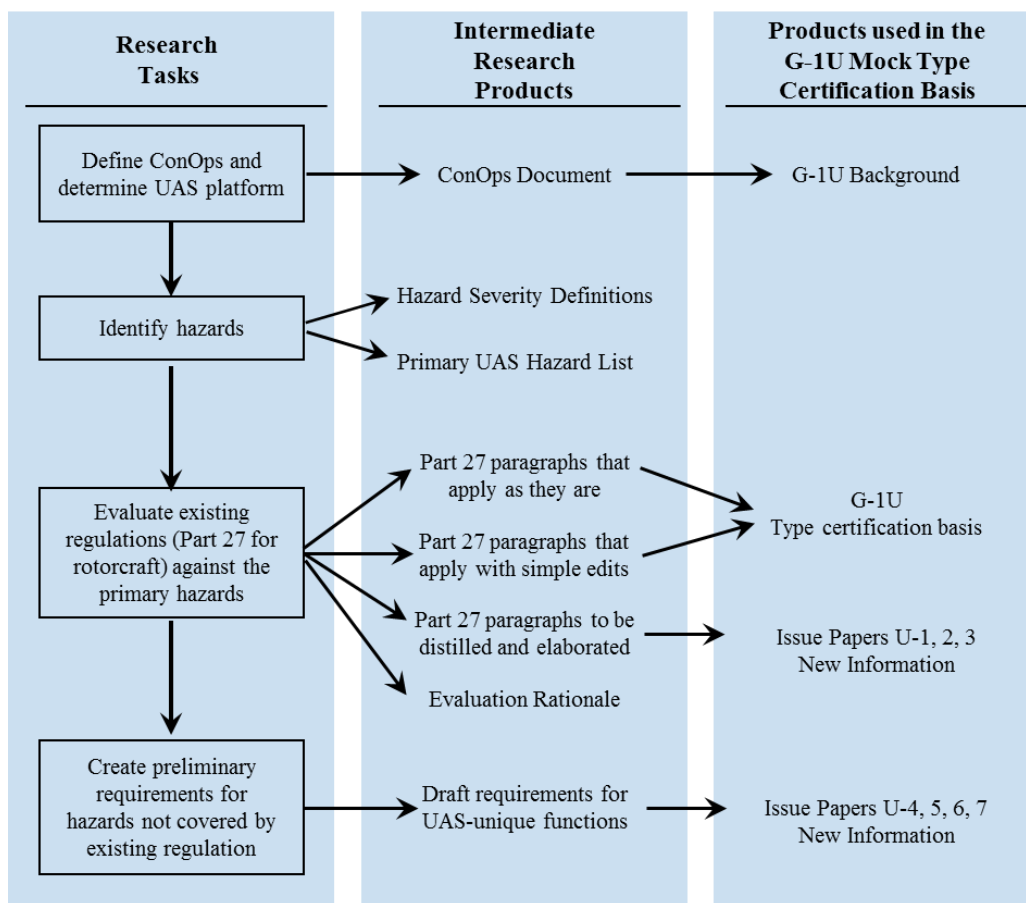


Figure 4. Overview of Research Approach

## 4.1. Task 1: Identifying Hazards

The approach to developing content for the mock type certification basis taken here is hazard-based; that is, the requirements in the certification basis are largely determined by the hazards and associated risks that need to be managed. Hazard and risk assessment processes are, by their nature, subjective. Alternative hazard and risk assessment techniques exist, and the discovery of new hazards or safety insights could alter the proposed certification basis.

Identifying hazards associated with the unmanned aerial applicator and its operation is fundamental to the approach used here. The first task was to identify hazards that could cause harm to people or property. These include UAS-specific hazards associated with the failure of aircraft functions and operational hazards associated with the mission and crew. Traditional aircraft hazards such as loss of control and loss of navigation were considered. New hazards related to the ConOps, such as loss of containment (i.e., exceeding the virtual boundary for the operation) were also considered.

To the extent possible, conventional system safety processes and tools from the civil aircraft domain were used to identify hazards for the unmanned aerial applicator. Guidance for operational safety assessment from RTCA DO-264 [22] was used to help identify and classify operational hazards based on the ConOps. DO-264 was written to support the use of data communication services such as data link, but its guidelines are fitting for UAS operational safety. The standard can be tailored for UAS requirements in a straightforward manner. Guidance on functional hazard assessment from SAE ARP 4761 [23] was used to help identify failure conditions and functional hazards specific to the UAS. ARP 4761 describes various assessment and analysis methods (e.g., functional hazard assessment, preliminary system safety assessment, and fault trees) useful for understanding and managing risks on a new aircraft program. These methods allow an aircraft developer to systematically examine the aircraft's functions, classify proposed failure conditions according to their severity, and suggest ways to mitigate expected hazards.

Traditional hazard categories (catastrophic, hazardous, major, minor, and no effect) are defined in FAA Advisory Circulars for different aircraft categories (e.g., FAA Advisory Circular 23.1309-1E for general aviation aircraft [24]). Because loss of life is a realistic expectation with loss of a CPA, hull loss is directly tied to the definition for catastrophic hazards. For UAS, a hull loss event is not necessarily catastrophic. Depending on the operational context, hull loss of a UAS may not present a safety risk to life at all. Consequently, the severity definitions were tailored for use in this study, as shown in Table 3.

The severity definitions in Table 3 are similar to those recently offered by JARUS [25] and EASA [26], but emphasize the safety role of the pilot and crew and replace emphasis on hull loss with language specific to safety margins. Per these definitions, hull loss without consequence to people would not be considered a loss or reduction of safety margin. Hull loss would be a loss of safety margin in operational environments where fatality is possible. Any event that would incapacitate the crew to the extent that they could not perform an assigned safety role, such as issuing a command for a contingency maneuver, would also be considered catastrophic.

The goal of the hazard assessment for this research was not a definitive assessment of severity for each hazard associated with the UAS, but a broader evaluation of whether the potential consequences of a hazard necessitate a design or performance standard comparable to those in Part 27. Only those hazards whose consequence was considered major or worse (hazardous or catastrophic) were included on a list of hazards that should be mitigated by requirements in a certification basis for an unmanned aerial applicator. Those hazards and the rationale for them (based on the severity of their consequence) are shown in Table 4.

Table 2. Proposed Definitions of Hazards Categories for UAS

<p>Catastrophic: Failure conditions that are expected to result in:</p> <ol style="list-style-type: none"> <li>1. fatality or fatal injury to any person;</li> <li>2. complete loss of safety margins (e.g., hull loss for a manned aircraft or fly away<sup>6</sup> for an unmanned aircraft); or</li> <li>3. complete loss of the UAS crew's ability to perform their safety role (e.g., from incapacitation).</li> </ol>
<p>Hazardous: Failure conditions that would reduce the capability of the aircraft or the ability of the crew to cope with adverse operating conditions to the extent that there would be the following:</p> <ol style="list-style-type: none"> <li>1. serious injury to any person;</li> <li>2. a large reduction in safety margins (e.g., loss of separation) or functional capabilities; or</li> <li>3. serious impairment of the crew's ability to perform their safety role (e.g., failure inducing a high workload).</li> </ol>
<p>Major: Failure conditions that would reduce the capability of the aircraft or the crew's ability to cope with adverse operating conditions to the extent that there would be:</p> <ol style="list-style-type: none"> <li>1. physical distress, possibly including injuries, to any person;</li> <li>2. a significant reduction in safety margins or functional capabilities; or</li> <li>3. a significant impairment of the crew's ability to perform their safety role (e.g., failure inducing a significant workload).</li> </ol>
<p>Minor: Failure conditions that would not significantly reduce aircraft safety and involve crew actions that are within their capabilities. Minor failure conditions may include:</p> <ol style="list-style-type: none"> <li>1. discomfort to any person;</li> <li>2. a slight reduction in safety margins or functional capabilities;</li> <li>3. a slight reduction in the crew's ability to perform their safety role (e.g., minor distraction or use of emergency procedures).</li> </ol>
<p>No Safety Effect: Failure conditions that would have no effect on safety (that is, failure conditions that would not affect the operational capability of the aircraft or impact the crew's ability to perform their safety role).</p>

Because hull loss is not catastrophic under the ConOps, a number of traditional CPA hazards, such as loss or degradation of thrust or inadequate fuel, are not considered primary hazards. Hazards relevant to security (such as failure to prevent unauthorized access to command/control link), or crew (such as failure to verify communication between UAS crew and pilot), were considered beyond the scope of airworthiness requirements. The list of hazards and hazard severity definitions strongly influence the design and performance criteria specified in the mock type certification basis, but are not explicitly included in it, as per Figure 4.

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<sup>6</sup> The term “fly away” is used in this report to mean “an interruption or loss of the control link, or when the pilot is unable to effect control of the aircraft and, as a result, the UA is not operating in a predictable or planned manner” [27]. A fly away event typically involves a UA that leaves its designated operational boundaries.

Table 3. Primary Hazards for the Unmanned Precision Agriculture Operations

<b>Hazard</b>	<b>Rationale (for why it should be addressed by regulation)</b>
1. Loss of C2 link used for contingency management (e.g., flight termination command issued from the ground control station)	Potential for large loss of functional capability and reduction in safety margin. For example, the pilot will not be able to issue a flight termination command if needed.
2. Loss of or degraded electrical power in the ground control station for contingency and emergency functions	Potential for large loss of functional capability and reduction in safety margin. For example, the pilot will not be able to issue a flight termination command if needed.
3. Loss of or degraded electrical power subsystems on UA for contingency and emergency functions	Potential for large loss of functional capability and reduction in safety margin. For example, a command for flight termination, if needed, may not be executed on the UA.
4. Loss or degradation of ground control station capability (e.g., loss of displays) required for contingency and emergency functions	Potential for large loss of functional capability and reduction in safety margin. For example, the pilot will not be able to issue a flight termination command if needed.
5. Loss of UAS position and anti-collision lights (loss of means to be seen by other aircraft and observers)	Potential for large or complete loss of functional capability affecting safety. For example, other aircraft may not see and hence, avoid the UA, and the crew may not be able to track the UA. Lighting is not relevant for daytime, VLOS operations.
6. Loss of or inadequate structural integrity, especially of the rotor system	Potential for fatality or fatal injury from high energy parts exiting the containment zone.
7. Loss of or degraded communication between pilot and crew	Potential for significant loss of functional capability and safety margin. For example, observers cannot communicate effectively or promptly with the pilot in cases where they need to provide safety alerts (about obstacles, incoming aircraft, or breach of boundary, etc.) in VLOS operations.
8. Failure to detect, alert or warn, and avoid intruder aircraft	Potential for complete loss of safety margin, leading to fatality or fatal injury. This includes observers failing to detect and warn about intruder aircraft, pilots failing to act to avoid the aircraft, or failure of an automated system to do so.
9. Failure to detect, alert or warn, and avoid dynamic or other obstacles on the ground	Potential for complete reduction in safety margin, leading to fatality or fatal injury. For example, crew may fail to detect a person or unplanned obstacle such as a tractor that may enter field in VLOS operations, or supporting onboard instrumentation may fail to detect and avoid obstacles.
10. Failure to recognize and avoid adverse environmental conditions (e.g., low visibility or high winds) beyond operational limits	Potential for large or complete reduction in safety margin. For example, crew may be unable to see the UA, intruder aircraft, or ground-based obstacles in poor visibility conditions and act as needed to avoid collisions.
11. Failure or degradation of the flight containment function	Potential for complete reduction in safety margin. For example, observers may fail to detect and notify pilot of impending violation of the containment boundary in VLOS operations or an automated system may fail to detect and avoid breach of the containment boundary.
12. Loss of situational awareness by the pilot	Potential for large or complete loss of safety margin. For example, without appropriate situational awareness, the pilot may not act when needed, or may take an inappropriate action. Loss of situational awareness may be due to inadequate or misleading flight data.
13. Interference of spray system with required UAS function	Potential for large or complete loss of functional capability or safety margin, on the UA or ground control station. For example, the spray system may affect the UA's aerodynamics and controllability.
14. Explosion in the powerplant or fuel system	Potential for fatality or fatal injury from high energy parts exiting the containment zone.
15. Failure to maintain adequate controllability, maneuverability, and stability	Potential for a significant loss of functional capability and safety margin, especially when operating near the edge of the containment volume. For example, loss of controllability may affect the UAs ability to stay within the containment boundary.



## 4.2. Task 2: Evaluating Applicability of Part 27

The second task was to specify reasonable design and performance criteria for the unmanned aerial applicator. The Part 27 standards for normal category rotorcraft and the UAS-tailored version from JARUS provided a practical starting point. Ideally, those standards mitigate airworthiness hazards for rotorcraft that are similar in many respects to the specimen unmanned rotorcraft. The need to prevent hull loss, however, is a significant difference. For this task, each paragraph in Part 27 was evaluated for applicability to the unmanned aerial applicator, with respect to the hazards in Table 4. That effort identified Part 27 regulations that apply “as is” to mitigate the primary hazards, those that apply with some simple modifications, and those that may not be applicable at all. As shown in Figure 4, the paragraphs accepted “as is” and those that were modified constitute the main set of requirements in the mock type certification basis for the unmanned rotorcraft.

Many of the Part 27 paragraphs, however, were not easy to place in one of those three categories. In particular, several Part 27 requirements that address controllability, maneuverability, and stability (CMS), structural integrity (SI), and powerplant and supporting systems (PPS) seemed applicable to some degree, but not as written nor easily modified. In some cases, the original requirement serves primarily to protect onboard crew and passengers, but might also protect crewmembers or others on the ground (e.g., from high energy debris). In other cases, the original requirement contains details very specific to normal category rotorcraft (e.g., limit load factors) that could not be easily modified without subject matter expertise and UAS-specific data. To address these issues, the relevant content from Part 27 requirements for CMS, SI, and PPS was generalized or “rolled up” into broad sets of requirements that focus on preservation of the rotor system to prevent harm from release of high energy debris and explosion. Each “roll-up” (CMS, SI, and PPS) allows all of the requirements on a topic to be considered in a holistic way in the context of the details of the design. The roll-up process resulted in three new technology issue papers included in the mock certification basis. Each Part 27 requirement included in one of those issue papers is explicitly enumerated in the corresponding issue paper. Requirements may appear in multiple new information issue papers.

Table 5 shows the disposition of the Part 27 regulations.

Table 4. Disposition of Part 27 Regulations for the Mock Type Certification Basis

Part 27	Included as Written	Included with Simple Modifications	Rolled Up	Excluded
Subpart A: General	0	0	0	2
Subpart B: Flight	1	1	14	11
Subpart C: Strength Requirements	0	2	10	25
Subpart D: Design and Construction	2	8	20	32
Subpart E: Powerplant	4	7	24	23
Subpart F: Equipment	1	22	1	16
Subpart G: Operating Limitations and Information	1	13	5	8
Appendix A: Instructions for Continued Airworthiness	2	2	0	0
Appendix B: Airworthiness Criteria for Helicopter Instrument Flight	0	0	0	1
Appendix C: Criteria for Category A	0	0	0	1
Appendix D: HIRF Environments and Equipment HIRF Test Levels	0	1	0	0
TOTAL	11	56	74	119

Altogether, of the 260 regulations contained in Part 27, only 11 are included as written in the certification basis: 119 regulations from Part 27 are outright excluded. Of the residual 130 regulations, 56 have had their text modified for inclusion in the certification basis, while the remaining 74 have had their intent abstracted into the three special issue papers for CMS, SI, and PPS. Thus, less than 5% of Part 27 was deemed applicable verbatim to the derived mock certification basis, with only an additional 22% suitable for textual modification.

The evaluation process is subjective by nature. As part of the evaluation process, rationale was documented for the disposition of each Part 27 paragraph. The rationale attempts to capture the reasoning used to determine the applicability of each Part 27 paragraphs to the unmanned rotorcraft with its ConOps. Rationale is not typically included in a type certification basis, but is provided with requests for exemptions. Here, the rationale helps shed light on why a paragraph was included, modified, or rolled up, in addition to reasons why a paragraph was not recommended for inclusion in the certification basis. The Appendix contains the rationale.

### **4.3. Task 3: Generating UAS-unique Requirements**

Lastly, the primary hazard list was reviewed to identify those hazards for which there are no applicable requirements from Part 27. The review identified four primary hazards that are not covered by paragraphs in Part 27:

- Loss of containment (i.e., a failure causing a fly away event where the UA leaves the operational area)
- Failure to detect and avoid people on the ground
- Failure of safety-critical C2 links
- Failure to detect and avoid other aircraft

The first three hazards are not addressed in any of the FARs, but the last hazard is related to standards for aircraft operators. FAR Part §91.113 requires an aircraft operator to use vigilance to see and avoid other aircraft. Because there is no onboard operator on a UAS, some systems and equipment will be required to accomplish that function. Those systems and that equipment would be subject to airworthiness regulation.

The third task involved drafting new requirements to address the containment system, systems for detecting and avoiding people and other aircraft, and for safety-critical datalinks. New Information Issue Papers were proposed for each of those and included in the mock type certification basis. Each of those issue papers explains why additional guidance is needed, provides background information explaining the hazard, and offers a mock regulatory position with high-level requirements aimed at mitigating the hazard. Like the G-1U Issue Paper, each of the new information issue papers is intended to serve as a starting point for discussion. None of the issue papers represents official FAA guidance.

The content of the mock type certification basis is given in the next Section.

## 5. Mock Type Certification Basis

Type certification is the foundation for most regulatory approvals related to airworthiness. A type certificate is issued when the regulator determines that a product's design complies with applicable regulations. The type design of an aircraft product is the engineering definition of the product, including (1) drawings and specifications, (2) dimensions, materials, and processes, (3) airworthiness limitations, and (4) other data to describe the product design [28]. The regulating body compares design documents and processes to determine if the design meets requirements established for the type of equipment. For example, FAR Part 27 contains the standards for normal-category rotorcraft. Once the type certificate is issued, the aircraft "type" is considered to meet appropriate requirements. Neither standards nor aircraft types have been established yet for UAS.

The FAA recommends starting a certification program with a set of plans to foster teamwork and an agreement on how product certification will be conducted. This agreement sets out general expectations, operating norms, communications protocols, schedule, and required deliverables [29]. The type certification process starts when an applicant submits FAA Form 8110-12 ("Application for Type Certificate, Production Certificate, or Supplemental Certificate") to the FAA. A UAS certification project in the US would likely start in the same way.

The FAA uses Issue Papers as a means to formally communicate with an applicant about their certification program. The Issue Paper process, as described in FAA Order 8110.112 [15], provides a means of tracking certification requirements and issues requiring resolution throughout an aircraft certification process. There are several different types of issues papers. The most germane to this study are the G-1 Certification Basis Issue Paper and New Information Issue Papers. The G-1 Issue Paper designates the applicable airworthiness and environmental (i.e., noise, fuel venting and exhaust emissions) regulations that constitute a type certification basis. New Information Issue Papers address new or novel technology that is not covered or covered adequately in existing regulation.

The mock type certification basis for the unmanned aerial applicator that follows is formatted like a G-1 Issue Paper with some minor deviations. The issue paper format was adopted because it is familiar to civil aircraft certification specialists and regulatory authorities. The mock type certification basis is labeled "G-1U" to indicate that the subject aircraft is unmanned. The G-1U includes a brief description of the concept of operations. This is atypical of a G-1 Issue Paper, but serves to provide operational information pertinent to airworthiness. Because there are no established airworthiness standards specific to UAS, the G-1U calls out requirements from Part 27 that apply in part or in whole to the applicant's aircraft. Text for each requirement can be found in the Appendix of this report. New Information Issue Papers are also included in the G-1U. These address the rolled-up requirements for CMS, SI, and PPS, and the UAS-unique systems described in Sections 4.2 and 4.3.

For this mock certification basis, the Acme-XYZ company is the fictitious name of the applicant for the type certificate and developer of the specimen unmanned aerial applicator (the AgR-1). The URA-123 is the fictitious name for the regulatory approval authority for the UAS. The content of the mock type certification basis does not represent the official position of the FAA or any other certification authority.

As a companion to the mock type certification basis, rationale for decisions made regarding the applicability of the Part 27 requirements to the AgR-1 was documented and included in the Appendix. The Appendix offers informal reasoning about each Part 27 requirement: why it is included in the mock type certification basis, why it is modified, why it is "rolled up", or why it is excluded. The intent, like the intent of the mock type certification basis, is to support debate about potential changes to existing regulations.

## 5.1. G-1U Issue Paper

Project:	Acme-XYZ Model AgR-1 Project No. TBD
Item:	G-1U
Stage:	1
Regulatory Reference:	14 CFR §21.17(b), Designation of Applicable Regulations
Date:	TBD
National Policy Reference:	FAA Order 8110.4C, Type Certification [28] FAA AC 27-1B, Certification of Normal Category Rotorcraft [30] FAA, Integration of Unmanned Aircraft Systems into the National Airspace System, Concept of Operations, v2.0 [31]
Issue Status:	Open
Subject:	Type Certification Basis
Branch Action:	URA-123 UAS Certification Branch
Compliance Target:	Pre-TC

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### TYPE CERTIFICATION BASIS

#### *Statement of Issue*

Acme-XYZ submitted an application (FAA Form 8110-12, dated MMDDYYYY, with cover letter Acme-XYZ-xxx-TBD) for Type Certification of the Acme AgR-1 unmanned rotorcraft. Project Number TBD has been assigned to the AgR-1 program. The following is the URA-123 position on the certification basis of the AgR-1 and those associated systems required for dispatch and aerial application operations within a defined volume of airspace.

In accordance with Title 14 Code of Federal Regulation (CFR) Part 21 requirements, the certification basis for the Acme-XYZ Model AgR-1 is established within this document. The certification basis, in addition to the applicable Federal Aviation Regulations, may include additional Issue Papers, Special Conditions, Equivalent Safety Findings, Exemptions, additional design requirements associated with any unsafe conditions operating requirements, and proposed amendments under review by the URA-123 and industry groups.

This certification basis is tightly coupled with the AgR-1's concept of operations for aerial application within a defined volume of airspace. In that concept, the UA is restricted to operating within a defined volume of airspace, referred to herein as a containment volume. No people are allowed within the containment volume when the UA is in flight. The pilot and other crew are located close to the containment volume, but not within it.

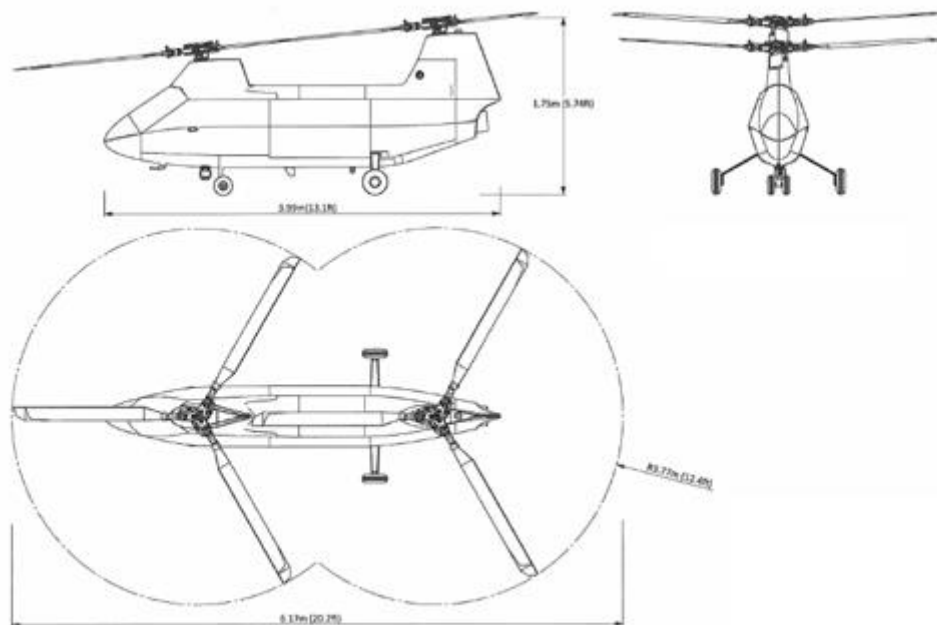
In this context, operational and functional hazards differ from those for manned aircraft. Consequently, many of the certification requirements in 14 CFR Part 27 for normal category rotorcraft are inappropriate as written for the AgR-1 in its intended operational environment. The requirements under this Type Certificate are contained in this Issue Paper, which is heavily based on Part 27. Additional issues and requirements, to be addressed under the Type Certificate, have been identified in supplemental issue papers for novel or unusual systems.

### *Background*

Acme-XYZ has provided the following description of its unmanned aircraft system and its concept of operations.

The AgR-1, depicted below, is an unmanned rotorcraft with the following configuration and characteristics.

- Tandem rotors
- Single turbine powerplant
- Physical envelope of 21 feet by 13 feet by 5.5 feet
- Maximum gross takeoff weight of approximately 1000 pounds (including max payload weight)
- Maximum endurance of 5 hours with no payload, 2.4 hours with 430-pound (maximum) payload
- Maximum airspeed of 100 knots
- Highly automated primary systems, including operator's ground control station



The concept of operations for the AgR-1 is for precision aerial application of chemicals to treat crops. The following operational characteristics are relevant to this type certification.

- The rotorcraft will operate only within a pre-defined containment volume.
- Operations will be conducted over farmland in rural, sparsely populated areas.
- The typical operational area will be ½ mile by ½ mile.

- Operations will typically be conducted only a few feet over crop height. Operation at more than 400 ft above ground level is prohibited.
- Operations will occur under visibility conditions including daytime, nighttime, and reduced visibility, both within and beyond visual line-of-sight.
- Inner loop control and normal outer loop control is provided by onboard automated systems. The remote pilot has final authority and responsibility for operation and safety of flight and can override outer loop control provided by the autopilot.
- Operations will recognize that other aircraft and people may enter the containment volume.

#### *Certification schedule*

Month Year [ed. note: nominally, application date + three years]

#### *URA-123 Position (Stage 1)*

As the applicant, Acme-XYZ is responsible for meeting all regulatory requirements contained in this Issue paper.

#### *Applicable FARs*

The following list includes those regulations from Part 27, by number and title, that apply to the Acme AgR-1. Some of those regulations have been modified as noted <sup>7</sup> to address unique aspects of the AgR-1 with respect to its intended operation.

#### Subpart B—Flight

##### General

§27.21	Proof of compliance <i>-modified</i>
§27.241	Ground resonance

#### Subpart C—Strength Requirements

##### Control Surface and System Loads

§27.411	Ground clearance: tail rotor guard <i>-modified</i>
§27.427	Unsymmetrical loads <i>-modified</i>

#### Subpart D—Design and Construction

##### General

§27.601	Design <i>-modified</i>
§27.602	Critical Parts <i>-modified</i>
§27.603	Materials
§27.609	Protection of structure <i>-modified</i>
§27.610	Lightning and static electricity protection <i>-modified</i>
§27.611	Inspection provisions <i>-modified</i>
§27.629	Flutter

##### Control Systems

§27.691	Autorotation control mechanism <i>-modified</i>
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##### Fire Protection

§27.861	Fire protection of structure, controls, and other parts <i>-modified</i>
§27.863	Flammable fluid fire protection <i>-modified</i>

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<sup>7</sup> The wording of proposed modifications to the requirements would be included in a type certification basis. To avoid replication in this document, the text and modifications are shown in the Appendix.

## Subpart E—Powerplant

### General

- §27.903 Engines *-modified*
- §27.907 Engine vibration *-modified*

### Rotor Drive System

- §27.917 Design *-modified*
- §27.921 Rotor brake
- §27.931 Shafting critical speed
- §27.935 Shafting joints
- §27.939 Turbine engine operating characteristics *-modified*

### Fuel System

- §27.969 Fuel tank expansion space
- §27.973 Fuel tank filler connection *-modified*
- §27.975 Fuel tank vents *-modified*

### Oil System

- §27.1027 Transmission and gearboxes *-modified*

## Subpart F—Equipment

### General

- §27.1301 Function and installation *-modified*
- §27.1303 Flight and navigation instruments *-modified*
- §27.1305 Powerplant limitations *-modified*
- §27.1307 Miscellaneous equipment *-modified*
- §27.1309 Equipment, systems, and installations *-modified*
- §27.1317 High-intensity Radiated Fields (HIRF) Protection *-modified*

### Instruments: Installation

- §27.1321 Arrangement and visibility *-modified*
- §27.1322 Warning, caution, and advisory lights *-modified*
- §27.1325 Static pressure systems *-modified*
- §27.1329 Automatic pilot system *-modified*

### Electrical Systems and Equipment

- §27.1351 General *-modified*
- §27.1353 Storage battery design and installation *-modified*
- §27.1357 Circuit protective devices *-modified*
- §27.1361 Master switch *-modified*
- §27.1365 Electric cables *-modified*
- §27.1367 Switches *-modified*

### Lights

- §27.1381 Instrument lights *-modified*
- §27.1383 Landing lights *-modified*
- §27.1397 Color specifications
- §27.1401 Anticollision light system *-modified*

### Safety Equipment

- §27.1411 General *-modified*
- §27.1459 Flight data recorders *-modified*
- §27.1461 Equipment containing high energy rotors *-modified*

## Subpart G—Operating Limitations and Information

- §27.1501 General *-modified*

#### Operating Limitations

- §27.1523 Minimum flight crew *-modified*
- §27.1525 Kinds of operations *-modified*
- §27.1527 Maximum operating altitude *-modified*
- §27.1529 Instructions for Continued Airworthiness - *modified*

#### Markings and Placards

- §27.1541 General *-modified*
- §27.1555 Control markings *-modified*
- §27.1557 Miscellaneous markings and placards *-modified*
- §27.1559 Limitations placard *-modified*
- §27.1561 Safety equipment *-modified*
- §27.1565 Tail rotor

#### Rotorcraft Flight Manual and Approved Manual Material

- §27.1581 General *-modified*
- §27.1583 Operating limitations *-modified*
- §27.1585 Operating procedures *-modified*

#### Appendix A—Instructions for Continued Airworthiness

- A§27.1 General *-modified*
- A§27.2 Format
- A§27.3 Content *-modified*
- A§27.4 Airworthiness Limitations section

#### Appendix D—HIRF Environments and Equipment HIRF Test Levels *-modified*

Fuel Venting and Exhaust Emission Requirements for Turbine Powered Aircraft [reworked Part 34, through Amendment TBD, as appropriate]

Noise Standards: Aircraft Type and Airworthiness Certification [reworked Part 36, through Amendment TBD, as appropriate (see also Title 49, USC, Section 44715, “Noise Control Act of 1972”)]

#### *Issue Papers*

The following issue papers apply to the AgR-1 type certification:

- Issue Paper U-1 Controllability, Maneuverability, and Stability
- Issue Paper U-2 Structural Integrity
- Issue Paper U-3 Powerplant and Supporting Systems
- Issue Paper U-4 Containment
- Issue Paper U-5 Detect and Avoid Intruder Aircraft
- Issue Paper U-6 Detect and Avoid Persons and Objects within the Containment Area
- Issue Paper U-7 Safety-critical Command and Control Datalinks

#### *Special Conditions*

Special Conditions will be issued as appropriate in accordance with 14 CFR Part 21, Section 21.16.

#### *Equivalent Safety Findings*

Equivalent Safety Findings (ESFs) will be administered in accordance with 14 CFR Part 21, Section 21.21. The URA-123 expects Acme-XYZ to submit a request and justification for each proposed ESF after more detailed design discussions with the URA-123 have taken place. If ESFs are submitted, the URA-123 will generate subsequent Issue Papers documenting agency findings.



### *Exemptions*

Acme-XYZ may petition the URA-123 to grant relief from current regulatory requirements. Petitions are to be submitted in accordance with 14 CFR Part 11, Sections 11.61 through 11.101.

### *Voluntary regulatory compliance*

Acme-XYZ may request that additional or optional design requirements be included in the AgR-1 certification basis.

### *Additional Design Requirements and Conditions*

Compliance with the established basis for Type Certification notwithstanding, 14 CFR 21.21(b)(2) precludes issuance of Type Certificate if any feature or characteristic of the product would make the product unsafe. Should the URA-123 determine that such an unsafe feature or characteristic exists, approval of the Type Certificate will be withheld pending acceptable corrective action by the applicant. Unsafe features or characteristics will be identified and resolved using Issue Papers. The requirements or conditions used to address unsafe features will be identified in the Type Certificate Data Sheet in a section immediately following specification of the certification basis.

### *Operating Certificate Requirements*

From time to time, amendments to the operating rules of 14 CFR can specify retroactive compliance under the relevant airworthiness requirements. Compliance with such amendments is mandatory for operation under the applicable operating rules. If not already included in the above certification basis, any such applicable airworthiness requirement may be added to the Type Certification Basis of the AgR-1 by mutual agreement between Acme-XYZ and the URA-123. The applicant should note, however, that compliance with any such retroactive mandate can affect the AgR-1 operator regardless of the contents of this G-1U Issue Paper.

### *Changes to the certification basis*

It is the URA-123's intent to define the AgR-1 certification basis by closing this G-1U Issue Paper early in the certification program. Any changes to the certification basis due to addition of new Special Conditions, Equivalent Safety Findings, Exemptions, or additional design requirements will be coordinated with Acme-XYZ by Issue Paper and added to the G-1U Issue Paper before issuance of the Type Certificate. The final certification basis will be summarized in the conclusion of this Issue Paper.

### *Acme-XYZ Position (Stage 1)*

TBD

### 5.1.1. U-1 Issue Paper: Controllability, Maneuverability, and Stability

Project:	Acme-XYZ Model AgR-1 Project No. TBD
Item:	Issue Paper U-1
Stage:	1
Date:	TBD
Regulatory Reference:	14 CFR §21.17(b), Designation of Applicable Regulations
National Policy Reference:	FAA Order 8110.4C, Type Certification [28] FAA AC 27-1B, Certification of Normal Category Rotorcraft [30]
Issue Status:	Open
Subject:	Controllability, Maneuverability, and Stability
Date:	TBD
Branch Action:	URA-123 UAS Certification Branch
Compliance Target:	Pre-TC
Type of Issue Paper	New Information

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#### *Statement of Issue*

Existing certification requirements in 14 CFR Part 27 for controllability, maneuverability, and stability (CMS) of a rotorcraft are inappropriate as written for the AgR-1 in its intended operational environment. Modifications to Part 27 are necessary to ensure the requirements related to CMS are appropriate for the AgR-1 and its operation under this Type Certificate.

#### *Background*

Part 27 is concerned with protection of flight crew and passengers. Conventional airworthiness requirements generally relate to such protection, though many requirements relate to protection indirectly. For example, traditional focus on vehicle damage and hull loss is invariably a proxy for underlying concern with the safety of all occupants aboard an aircraft. The hazards associated with operation of an unmanned aerial applicator, however, differ greatly from those addressed by Part 27. In particular, the possibility of injury to or death of bystanders from high-energy debris becomes a key concern.

Several failure conditions can result in high-energy debris. This Issue Paper addresses one family of those conditions: inadequate controllability and maneuverability of the UA in circumstances that can lead to rotor, hub, or drive system damage and subsequent release of high-energy debris (e.g., rotor blades) near humans.

The Type Design must incorporate provisions, design features, and characteristics that reduce to acceptable levels the risks associated with, for example, (a) loss of control during takeoff, leading to

vehicle rollover and destruction of the main rotors near ground personnel, or (b) loss of control during hover near the containment boundary, leading to uncontrolled descent into terrain near UAS observers or even unrelated bystanders outside the containment zone.

#### *URA-123 Position (Stage 1)*

As the applicant, Acme-XYZ is responsible for meeting all regulatory requirements, both existing requirements and those requirements unique to AgR-1 Type Certification, as agreed to between the URA-123 and the applicant. Acme-XYZ must address the concerns expressed in this Issue Paper as they pertain to the specified vehicle characteristics.

The applicant must meet the regulatory intent of requirements related to controllability, stability, maneuverability, and control system design and installation, notably those requirements embodied in 14 CFR Part 27, Subparts B and C indicated in Notes 1 and 2. The URA-123 recognizes that tradeoffs exist between operational mitigations and traditional handling of functional capabilities, integrity, and design assurance, and that improvements in one area can compensate for deficiencies in the other. The URA-123 encourages the applicant to clarify and to make explicit such tradeoffs in its proposed type design.

The applicant must:

(a) establish controllability and maneuverability design margins that prevent (i) contact of the vehicle rotors with the ground, other parts of the vehicle structure, or obstacles in normal and non-normal operations and (ii) any other condition that could compromise rotor system integrity. The applicant must demonstrate that the proposed control system design and installation meets or exceeds these requirements. Considerations include but are not limited to the following:

- critical values of design parameters including weight, center of gravity, rotor speed, speed, density altitude, and height-speed envelope,
- normal operations such as takeoff, landing, and spraying and critical values of operational parameters such as winds, slopes, etc. for which operational approval is sought, and
- non-normal operations such as autorotation and contingency maneuvers.

Note 1: The following requirements from Part 27 are relevant to (a): §27.25, §27.27, §27.33, §27.51, §27.75, §27.87, §27.141, §27.143, §27.151, §27.173, §27.175, §27.177, §27.231, §27.321, §27.337, §27.672, §27.1151(a) only, §27.1519, §27.1583, §27.1587, and §27.1589.

(b) ensure that flight control commands from all sources (stability augmentation system, autopilot, GCS, etc.) are passed to the appropriate flight control surfaces without hazardous flexure, slop, friction, jamming, interference or other hazards that would lead to loss of rotor system integrity. This requirement must cover all normal and non-normal operational conditions that may reasonably be expected in service. This requirement includes the electrical and mechanical aspects of the control system, and includes control of engines, rotor brakes, and other elements of the design that involve automated or remote operation of the vehicle controls.

Note 2: The following requirements from Part 27 are relevant to (b): §27.307, §27.309, §27.391, §27.395, §27.605, §27.607, §27.621, §27.623, §27.625, §27.671, §27.675, §27.679, §27.681, §27.683, §27.685, §27.687, and §27.695.

#### *Acme-XYZ Position (Stage 1):*

TBD

### 5.1.2. U-2 Issue Paper: Structural Integrity

Project:	Acme-XYZ Model AgR-1 Project No. TBD
Item:	Issue Paper U-2
Stage:	1
Date:	TBD
Regulatory Reference:	14 CFR §21.17(b), Designation of Applicable Regulations
National Policy Reference:	FAA Order 8110.4C, Type Certification [28] FAA AC 27-1B, Certification of Normal Category Rotorcraft [30]
Issue Status:	Open
Subject:	Structural Integrity
Date:	TBD
Branch Action:	URA-123 UAS Certification Branch
Compliance Target:	Pre-TC
Type of Issue Paper	New Information

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#### *Statement of Issue*

Existing certification requirements in 14 CFR Part 27 for structural integrity of rotor and hub assemblies, supporting structure, and drive systems are inappropriate as written for the AgR-1 in its intended operational environment. Modifications to relevant paragraphs of Part 27 are necessary to ensure the requirements related to structural integrity are appropriate for the AgR-1 rotor, hub, and drive systems.

#### *Background*

Part 27 is concerned with protection of flight crew and passengers. Conventional airworthiness requirements generally relate to such protection, though many requirements relate to protection indirectly. For example, traditional focus on vehicle damage and hull loss is invariably a proxy for underlying concern with the safety of all occupants aboard an aircraft.

The hazards associated with operation of an unmanned aerial applicator, however, differ in many respects from those addressed by Part 27. In particular, the possibility of injury to or death of crew or bystanders from high-energy debris becomes a key concern.

Several failure conditions can result in high-energy debris. This Issue Paper addresses one family of those conditions: inadequate structural integrity of the UA's rotor system in circumstances that can lead to rotor, hub, or drive system failure and subsequent release of high-energy debris near humans.

### *URA-123 Position (Stage 1)*

As the applicant, Acme-XYZ is responsible for meeting all regulatory requirements, both existing requirements and those requirements unique to AgR-1 Type Certification, as agreed to between the URA-123 and the applicant. Acme-XYZ must address the concerns expressed in this Issue Paper as they pertain to the specified vehicle characteristics.

The applicant must meet the regulatory intent of structural requirements, notably those requirements embodied in 14 CFR Part 27, Subpart C (see Note). The URA-123 recognizes that tradeoffs exist between operational mitigations and traditional structural requirements, and that improvements in one area can compensate for deficiencies in the other. The URA-123 encourages the applicant to clarify and to make explicit such tradeoffs, if included, in its proposed type design.

The Type Design must incorporate provisions, design features, and characteristics that provide acceptable levels of protection against rotor, hub, and drive system failures.

The applicant must establish design margins and limitations of the structure of the rotor, hub, and drive systems to prevent loss of rotor system integrity (including primary load paths affecting the rotor system). The design margins and limitations should cover all conditions likely to be encountered in normal and non-normal operations. Considerations include but are not limited to static analysis, dynamic analysis, and fatigue analysis and testing at critical conditions of weight, center of gravity, engine/rotor speed, engine/rotor torque, ground resonance, and sudden stoppage of rotor and hub assemblies due to internal failure or seizure of internal components.

Note: The following requirements are relevant: §27.25, §27.27, §27.33, §27.51, §27.75, §27.141, §27.251, §27.307, §27.309, §27.321, §27.337, §27.391, §27.547, §27.549, §27.571, §27.605, 27.607, §27.621, §27.623, §27.625, §27.653, §27.659, §27.661, §27.663, §27.681, §27.1151 (a only), §27.1193, §27.1509, and §27.1583.

### *Acme-XYZ Position (Stage 1)*

TBD

### 5.1.3. U-3 Issue Paper: Powerplant and Supporting Systems

Project:	Acme-XYZ Model AgR-1 Project No. TBD
Item:	Issue Paper U-3
Stage:	1
Date:	TBD
Regulatory Reference:	14 CFR §21.17(b), Designation of Applicable Regulations
National Policy Reference:	FAA Order 8110.4C, Type Certification [28] FAA AC 27-1B, Certification of Normal Category Rotorcraft [30]
Issue Status:	Open
Subject:	Powerplant and Supporting Systems
Date:	TBD
Branch Action:	URA-123 UAS Certification Branch
Compliance Target:	Pre-TC
Type of Issue Paper	New Information

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#### *Statement of Issue*

Existing certification requirements in 14 CFR Part 27 for the powerplant and supporting systems (e.g., fuel, oil, cooling, exhaust, and induction systems) of a rotorcraft are overly prescriptive for the AgR-1 in its intended operational environment. Modifications to Part 27 are necessary to ensure the requirements related to the powerplant and supporting systems are appropriate for the AgR-1 under this Type Certificate.

#### *Background*

Part 27 requires high levels of powerplant reliability in order to protect occupants of the rotorcraft. By contrast, hull loss of an AgR-1 operating in accordance with approved operations has no safety effect. Thus, correspondingly lower reliability of the powerplant and its associated systems and the absence of an autorotation capability are generally acceptable under this type certificate. As such, many of the Part 27 requirements for the powerplant and supporting systems are not applicable to the AgR-1.

Lower levels of powerplant reliability, however, could expose the ground crew or the general public to harm. For example, flying debris might escape the containment area if a powerplant failure or seizure causes loss of rotor system integrity near a containment boundary. 14 CFR §27.917 requires the incorporation of a unit (e.g., a clutch) to automatically disengage the engine from the main and auxiliary rotors if the engine fails. The purpose of this requirement is to protect the rotor drive system, which includes any part necessary to transmit power from the engine to the rotor hubs including “gear boxes,

shafting, universal joints, couplings, rotor brake assemblies, clutches, supporting bearings for shafting, attendant accessory pads or drives, and any cooling fans that are part of, or attached to, or mounted on the rotor drive system.” This Issue Paper assumes the inclusion of this requirement in the Type Certification Basis for the AgR-1, and addresses additional requirements on the powerplant and supporting systems necessary to preserve rotor system integrity.

*URA-123 Position (Stage 1):*

As the applicant, Acme-XYZ is responsible for meeting all regulatory requirements, both existing requirements and those requirements unique to AgR-1 Type Certification, as agreed to between the URA-123 and the applicant. Acme-XYZ must also address the concerns expressed in this Issue Paper as they pertain to the specified vehicle characteristics.

The Type Certification Basis for the AgR-1 must include 14 CFR §27.917 requiring a device that prevents engine failure or seizure from adversely affecting rotor system integrity. The applicant must also meet the regulatory intent of powerplant and supporting systems requirements, notably those requirements embodied in 14 CFR Part 27, Subpart E (see Note). The URA-123 recognizes that tradeoffs exist between operational mitigations and traditional handling of functional capabilities, integrity, and design assurance, and that improvements in one area can compensate for deficiencies in the other. The URA-123 encourages the applicant to clarify and to make explicit such tradeoffs in its proposed type design.

For the rotorcraft powerplant, powerplant installation, and associated systems (e.g., fuel, oil, ventilation, exhaust, and air induction systems), including relevant elements of the ground support equipment, the applicant:

- (a) must provide adequate protection to the ground crew during servicing and inspection of the rotorcraft for preflight, postflight, and thru-flight servicing,
- (b) may include credit for ground crew safety equipment, training, and operational procedures, and
- (c) may not include credit for ground-based protective barriers that only protect the crew.

Note: The following requirements are relevant: §27.963, §27.993, §27.995, §27.1121, §27.1183, §27.1185, §27.1187, §27.1189, §27.1191, §27.1193, §27.1521, and §27.1583.

*Acme-XYZ Position (Stage 1):*

TBD

#### 5.1.4. U-4 Issue Paper: Containment

Project:	Acme-XYZ Model AgR-1 Project No. TBD
Item:	Issue Paper U-4
Stage:	1
Date:	TBD
Regulatory Reference:	14 CFR §21.16, Special Conditions
National Policy Reference:	FAA Order 8110.4C, Type Certification [28]
Issue Status:	Open
Subject:	Containment
Date:	TBD
Branch Action:	URA-123 UAS Certification Branch
Compliance Target:	Pre-TC
Type of Issue Paper	New Information

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##### *Statement of Issue*

The concept of operations for the Acme AgR-1 is based on the provision of a geospatial containment function to confine operations to a defined volume of airspace. Geospatial containment systems are not addressed by existing regulation. New requirements are needed.

##### *Background*

The applicant has proposed a high-confidence geospatial containment function (that is, a means of ensuring that UA operations are confined within defined geospatial boundaries) to address hazards to other airspace users and people on the ground, especially in a loss of control event. For manned aircraft, highly reliable systems, equipment, and crew are relied upon to mitigate those hazards. Avionics systems for many unmanned aircraft do not meet the same levels of reliability or integrity. Consequently, alternative approaches to hazard mitigation might be needed to provide an acceptable level of safety. When combined with systems and procedures for ensuring that the containment volume remains clear of all persons, this approach is expected to provide sufficient mitigation of catastrophic hazards.

Availability and integrity requirements for normal category rotorcraft systems and equipment are specified in 14 CFR §27.1309. Paragraphs (a) and (c) of this regulation state: “(a) The equipment, systems, and installations whose functioning is required by this subchapter must be designed and installed to ensure that they perform their intended functions under any foreseeable operating condition” and “(c) The equipment, systems, and installations of single-engine rotorcraft must be designed to minimize hazards to the rotorcraft in the event of a probable malfunction or failure.”



Commercially available avionics systems that satisfy those requirements do not typically meet the size, weight, volume, and power limitations of the AgR-1 design. Consequently, the reliability level of systems and equipment on board the AgR-1 might not be sufficient to mitigate hazards, especially those associated with a fly-away event, without the addition and proper functioning of an independent, high-confidence containment system.

The following definitions relevant to containment apply:

- The *containment area* is a geographic area over which all UAS flight operations will be conducted.
- The *containment boundary* is a virtual surface defined around the containment area. The containment boundary is defined by the horizontal dimensions of the containment area and by a vertical height. Depending on system implementation, this boundary could be a simple geometric shape (e.g., cylinder or dome) or a complex multipoint closed surface.
- The *containment volume* is the volume of airspace enclosed by the boundary.
- The *containment system* is some combination of people, systems, and equipment used to confine the operation of a UA to a defined geospatial area.

Geofencing is a proposed means of confining the operation of a UAS to a defined area. Geofences are primarily implemented via software and the UA's autopilot, using the same sensors, actuators and processor as the vehicle's primary autopilot/control system. Such geofences generally suffer from multiple single points of failure, including the autopilot and global positioning system (GPS), making it difficult to achieve levels of reliability and design assurance adequate to meet typical airworthiness standards.

#### *URA-123 Position (Stage 1)*

The URA-123 recognizes that the applicant may, in order to prevent fly-away events, make trade-offs among procedures, operational limitations, and the functional capabilities of systems and equipment. The applicant must provide a containment system that addresses hazards associated with fly-away events. Any containment system must have the ability to detect impending violations of any containment boundary and take timely action to ensure the boundary is not crossed.

The applicant must provide a means to detect and avoid transgression of any containment boundaries established for the operation. This includes the following considerations:

- (a) The accuracy of the UAS's estimation of the UA's position relative to the containment boundaries must be sufficient to ensure that the aircraft will not exit a containment boundary.
- (b) Situational awareness of the UA's location relative to the containment boundaries should be maintained at all times during all flight operations.
- (c) Failure of infrastructure not part of the UAS (e.g., GPS, cellular telephone) must not significantly interfere with the determination of the location of the aircraft.
- (d) Means of detection should:
  - (1) have complete and unobstructed surveillance of any established containment boundaries, at all times during all flight operations in all weather conditions (e.g., lighting and visibility conditions) for which operations are approved; and
  - (2) be able to determine impending violations of any established boundary, in sufficient time for action to avoid crossing the boundary.
- (e) If action by the pilot in command is required to ensure the UA does not cross any established containment boundary, quick acting means must be provided to alert the pilot in command.

- (1) Timing thresholds for alerts should consider the time needed (i) to transmit data via radios or other means of communication, (ii) for ground control station processing and annunciation, and (iii) for human response, as relevant.
- (f) Means of avoidance must be sufficient to ensure the UA remains within the established containment boundaries at all times.
  - (1) Latency and availability of any command and control datalink or other communication links required for avoidance should be considered in establishing timing thresholds for avoidance maneuvers and shown to be acceptable for ensuring an avoidance maneuver can be executed to maintain containment.
  - (2) Activation of an avoidance maneuver from on board the UA must be communicated to the pilot in command in a timely manner.
  - (3) Confirmation of the completion of any avoidance maneuver must be communicated to the pilot in command in a timely manner.
- (g) The containment system design must consider events wherein release of high energy parts may constitute a hazard to bystanders outside the containment area.
- (h) The performance of the containment system must not be degraded by any form of interference under any foreseeable operating condition. Considerations should include, but are not limited to:
  - (1) electromagnetic interference caused by any other UA systems,
  - (2) electromagnetic interference external to the UA, and
  - (3) interference via acoustic, thermal, vibrational, chemical, or metallurgical means.

*Acme-XYZ Position (Stage 1)*

TBD

### 5.1.5. U-5 Issue Paper: Detect and Avoid Intruder Aircraft

Project:	Acme-XYZ Model AgR-1 Project No. TBD
Item:	Issue Paper U-5
Stage:	1
Date:	TBD
Regulatory Reference:	14 CFR §21.16, Special Conditions
National Policy Reference:	FAA Order 8110.4C, Type Certification [28]
Issue Status:	Open
Subject:	Detect and Avoid Intruder Aircraft
Date:	TBD
Branch Action:	URA-123 UAS Certification Branch
Compliance Target:	Pre-TC
Type of Issue Paper	New Information

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#### *Statement of Issue*

The AgR-1 must comply with the intent of 14 CFR Part §91.111(a), Operating Near Other Aircraft, and Part §91.113(b), Right-of-way Rules. Because there is no pilot on board the AgR-1 who can see and avoid other aircraft, additional systems, equipment, and procedures may be required to detect and avoid other aircraft that might enter the containment volume or come within close proximity to the AgR-1. An intruder aircraft detection and avoidance system is not addressed by existing regulation. New requirements are needed.

#### *Background*

14 CFR Part §91.111 (a) states that no person may operate an aircraft so close to another aircraft as to create a collision hazard and Part §91.113(b) states that vigilance shall be maintained by each person operating an aircraft so as to see and avoid other aircraft.

For manned aircraft, the pilot—with the assistance of systems such as air traffic control (ATC) and the Traffic Collision Avoidance System (TCAS)—is relied upon to keep the aircraft well clear of other aircraft. For unmanned aircraft, no equivalently safe and cost-effective civil airborne system exists at this time. The applicant has thus proposed a ground-based intruder aircraft detection and avoidance system to address hazards to other airspace users. To provide a cost-effective solution, this ground-based detect and avoid system might not provide the full functionality of human see and avoid. To compensate for this inadequacy, larger safety margins for the detect and avoid function should be provided. Requirements

appropriate for this alternative approach to avoiding other aircraft are needed to provide an acceptable level of safety.

*URA-123 Position (Stage 1)*

The URA-123 recognizes that the applicant may, in order to ensure separation, make trade-offs among procedures, operational limitations, and the functional capabilities of systems and equipment. The applicant must provide a system that addresses hazards associated with loss of separation. Any such system must have the ability to detect imminent intrusion or close proximity and take timely action to ensure separation is not lost.

The applicant should provide a means to detect and avoid other aircraft that may intrude on the containment volume or otherwise pose a threat to loss of separation. All other airborne vehicles, including other UA, should be given priority. The AgR-1 is responsible for remaining well clear of all other aircraft.

(a) Means of detecting other aircraft will:

- (1) be able to detect other airborne vehicles at a sufficient range from the containment area to allow time for an avoidance maneuver,
- (2) have complete and unobstructed coverage of the containment area, and
- (3) be active at all times during all flight operations in all weather, lighting, and visibility conditions for which operations are approved.

(b) If action by the pilot in command is required to avoid loss of separation with an airborne vehicle, quick acting means must be provided to alert the pilot in command.

- (1) Timing thresholds for alerts should consider the time needed (i) to transmit data via radios or other means of communication, (ii) for ground control station processing and annunciation, and (iii) for human response, as relevant.

(c) Means of avoidance must be sufficient to ensure the UA maintains sufficient separation from other aircraft at all times.

- (1) Latency and availability of any command and control datalink or other communication links required for avoidance should be considered in establishing timing thresholds for avoidance maneuvers and shown to be acceptable for ensuring an avoidance maneuver can be executed to maintain separation.
- (2) The avoidance maneuver must maintain separation throughout its execution duration.
- (3) Confirmation of any avoidance maneuver must be communicated to the pilot in command.
- (4) Clearance distances from containment boundaries should be established and maintained for avoidance maneuvers to ensure that no harm is done to persons on the ground.
- (5) Operations may only resume when the UA is well clear of all other aircraft.

(d) The performance of the aircraft detection and avoidance system must not be degraded by any form of interference under any foreseeable operating conditions. Considerations include, but are not limited to:

- (1) electromagnetic interference caused by any other UA systems,
- (2) electromagnetic interference external to the UA, and
- (3) interference via acoustic, thermal, vibrational, chemical or metallurgical means.

*Acme-XYZ Position (Stage 1)*

TBD

### 5.1.6. U-6 Issue Paper: Detect and Avoid Persons and Objects within the Containment Area

Project:	Acme-XYZ Model AgR-1 Project No. TBD
Item:	Issue Paper U-6
Stage:	1
Date:	TBD
Regulatory Reference:	14 CFR §21.16, Special Conditions
National Policy Reference:	FAA Order 8110.4C, Type Certification [28]
Issue Status:	Open
Subject:	Detect and Avoid Persons and Objects within the Containment Area
Date:	TBD
Branch Action:	URA-123 UAS Certification Branch
Compliance Target:	Pre-TC
Type of Issue Paper	New Information

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#### *Statement of Issue*

Although operational procedures are required to clear the containment area prior to flight operations, a system for detecting and avoiding people or obstacles within the containment area or that might enter the containment area during flight operations is required to avoid injuring persons or causing an impact that releases high energy part that could harm others. However, such a system is not addressed by existing regulation. New requirements are needed.

#### *Background*

Low-altitude flight such as that expected with aerial application operations poses hazards to people who might inadvertently enter the containment area defined for those operations. A low-altitude flight path might also encounter objects such as livestock or tractors that have been left in the field that could cause damage and potential release of high energy parts if struck with a rotorcraft. Because there is no pilot on board the AgR-1 who can see and avoid these obstacles, additional operational procedures, systems, and equipment not covered in Part 27 are required to monitor the containment area for people and obstacles and ensure that the AgR-1 does not collide with them.

Static obstacles (e.g., barns or silos) are mapped in advanced and loaded into a database a priori to operations for the purpose of path planning. Trajectories that are flown by the UA are designed to avoid these static obstacles. The proposed system can compensate for accuracy errors in the static object database or in path-following logic. Other obstacles such as mobile irrigation equipment may not be identified in static obstacle databases. Collision with sizable obstacles could cause release of high energy parts that

could pose harm to people beyond the containment zone. Unanticipated ground objects that have the potential to damage the rotor system of the AgR-1 on impact should be detected and avoided.

Dynamic objects (e.g., people wandering into the containment area, ground vehicles, livestock, or wildlife) cannot be planned for and must be avoided as they are detected.

#### *URA-123 Position (Stage 1)*

The URA-123 recognizes that the applicant may, in order to prevent collisions with people or obstacles within the containment area, make trade-offs among procedures, operational limitations, and the functional capabilities of systems and equipment.

The applicant must provide an appropriate detection and avoidance system that addresses hazards associated with harming any third parties resulting from colliding with objects within the containment area. Any such system must have the ability to detect persons or objects within the containment area and take timely action to ensure the UA does not collide with them or come within sufficient proximity to cause harm.

The applicant must provide a means to detect and avoid persons and objects within the defined operational area during flight operations.

##### (a) Means of detection will:

- (1) have sufficient range in the direction of UA travel to permit a simple avoidance maneuver (e.g., hovering or landing), and
- (2) provide detection during all flight operations in all weather, lighting, and visibility conditions for which operations are approved.

##### (b) If action by the pilot in command is required to avoid collision or remain a safe distance from persons or objects to prevent harm, quick acting means will be provided to alert the pilot in command.

- (1) Timing thresholds for alerts should consider the time needed (i) to transmit data via radios or other means of communication, (ii) for ground control station processing and annunciation, and (iii) for human response, as relevant.

##### (c) Means to suspend operation or provide an otherwise safe state shall be provided.

- (1) Latency and availability of any command and control datalink or other communication links required for avoidance should be considered in establishing timing thresholds for avoidance maneuvers and shown to be acceptable.
- (2) Minimum clearances should be established.
- (3) Confirmation of any avoidance maneuver should be communicated to the pilot in command in a timely manner.
- (4) Operations may only resume when the operational area has been cleared.

##### (d) The performance of the detection and avoidance system must not be degraded by any form of interference under any foreseeable operating conditions. Considerations include, but are not limited to:

- (1) electromagnetic interference caused by any other UA systems,
- (2) electromagnetic interference external to the UA, and
- (3) interference via acoustic, thermal, vibrational, chemical or metallurgical means.

#### *Acme-XYZ Position (Stage 1)*

TBD

### 5.1.7. U-7 Issue Paper: Safety-critical Command and Control Datalinks

Project:	Acme-XYZ Model AgR-1 Project No. TBD
Item:	Issue Paper U-7
Stage:	1
Date:	TBD
Regulatory Reference:	14 CFR §21.16, Special Conditions
National Policy Reference:	FAA Order 8110.4C, Type Certification [28]
Issue Status:	Open
Subject:	Safety-critical Command and Control Datalinks
Date:	TBD
Branch Action:	URA-123 UAS Certification Branch
Compliance Target:	Pre-TC
Type of Issue Paper	New Information

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#### *Statement of Issue*

Airworthiness of the UAS will be dependent on the quality of the command and control (C2) links. The quality of the C2 links is strongly influenced by the operational coverage and the various quality-of-service parameters of the communication media used. C2 link communications are necessary for a remote pilot to command the UA, especially to execute a safety role (e.g., by commanding safety-related maneuvers). A safety-critical C2 link is defined as a link which passes commands relevant to safety-critical functions. Currently, safety-critical C2 links are not addressed by existing regulation. New requirements are needed.

#### *Background*

Within the US, telecommunications services for the purposes of ATC are operated by the FAA. This will likely not be the case for UAS operations. Telecommunications services might be furnished by a broad variety of service providers. The frequency asset being used might be shared among radio communication providers over the operational area and might not be protected against interference (i.e., it might not be an aeronautical safety allocation).

Only UAS with remote pilots are currently eligible for certification consideration. Because C2 links are not standard equipment for manned aircraft, Part 27 does not include requirements for them. A UAS might include any number of datalinks, but not all datalinks have safety significance. This issue paper addresses only those datalinks that have a safety-critical role. As an aircraft's airworthiness can be rated with different capabilities based on the certification of the various components (e.g., for extended oceanic operations), it is conceivable that this might hold true with respect to the various types and

implementations of safety-critical C2 links. The URA-123 position is predicated on the following assumptions:

- There is a unique pairing between the ground control station and the aerial vehicle. That is, each vehicle is controlled by one unique ground control station (no handoffs between ground control stations, or simultaneous control over multiple ground control stations), and each ground control station only controls one unique vehicle (no control of multiple vehicles by a single ground control station or operator).
- The UA is within radio line-of-sight (RLOS) of the ground control station at all times during the operation, thus requiring no signal relays or repeaters.

#### *URA-123 Position (Stage 1)*

The applicant must include at least one safety-critical C2 link in the design of the AgR-1 for use by the pilot to command the UA to a safe state and for providing safety-critical data from the UA to the pilot. Any datalink referred to below is assumed to be safety-critical.

(a) The C2 link shall:

- (1) be available in all vehicle attitudes under all foreseeable operating conditions throughout the containment volume, and
- (2) enable radio line-of-sight communication for safety-critical data at all points throughout the entire containment volume.

(b) Uplink and downlink status shall be indicated to the pilot during all flight operations.

(c) The uplink(s) used to communicate the pilot commands to the UA will:

- (1) adhere to appropriate standards<sup>8</sup> of integrity, availability, continuity, reliability, and security;
- (2) cause operations to cease if thresholds for latency or for error rates are not met; and
- (3) be active at all times during all flight operations, including during all weather, lighting, and visibility conditions for which operations are approved.

(d) The downlink(s) used to communicate safety-critical vehicle information to the pilot in command will:

- (1) adhere to standards of integrity, availability, continuity, reliability, and security;
- (2) meet established standards for error rates; and
- (3) be capable of communicating data from the UA at all times during all flight operations in all weather, lighting, and visibility conditions for which operations are approved.

(e) The performance of the C2 link (e.g., availability and quality of service) must not be degraded by any form of interference under any foreseeable operating conditions. Considerations include, but are not limited to:

- (1) electromagnetic interference caused by any other UA system,
- (2) electromagnetic interference external to the UA,
- (3) ionospheric, atmospheric, or rain attenuation,
- (4) malicious interference/spoofing or link takeover,

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<sup>8</sup> Specification of standards for integrity, availability, continuity, reliability, and security are beyond the scope of this effort. Such standards may be developed by the FAA or standards groups such as the RTCA.



- (5) frequency access scheme, link budget, bandwidth characteristics and frequency assignment planning criteria of the C2 link,
- (6) adjacent or shared frequencies, and
- (7) interference related to shared resources (e.g., power).

*Acme-XYZ Position (Stage 1)*

TBD

## 6. Potential Systems and Equipment Implementation

The ConOps and mock type certification basis are useful only if UAS technology exists that can meet the objectives of the ConOps and can comply with the proposed design and performance standards. This section describes one possible UAS configuration that could meet those requirements. The example configuration is based in large part on Dragonfly Pictures' DP-14 model unmanned rotorcraft. This example configuration is used for illustrative purposes only and is not meant as an endorsement in any way. The DP-14 is currently under development by DPI. As such, some of the subsystems necessary to safely perform the aerial spray application are hypothesized (e.g., the containment system). Details of the example implementation are provided here to confirm the feasibility of developing a UAS with existing technology that can accomplish the aerial application mission and meet the speculated safety requirements.

The example configuration is described in terms of the following subsystems:

- DP-14 unmanned rotorcraft
- Ground control station
- Command and control datalink
- Positioning system
- Containment system
- Ground-based detect and avoid system
- Active obstacle avoidance system
- Payload and Spray Equipment
- Support Equipment

### 6.1. DP-14 Unmanned Rotorcraft

An unmanned, tandem-rotor, turbine-powered aircraft is one possible option for meeting the payload, transportability, and maneuverability requirements of the ConOps. The DP-14, shown in Figure 5, is one such rotorcraft. The rotorcraft has folding or removable blades to allow transportation by road between application sites and external hard points to allow installation of a spray system. An artist's conception of this rotorcraft with spray attachment is shown in Figure 6. The DP-14 is expected to have a payload capacity of approximately 430 lb and a total vehicle gross weight of 900 lb.

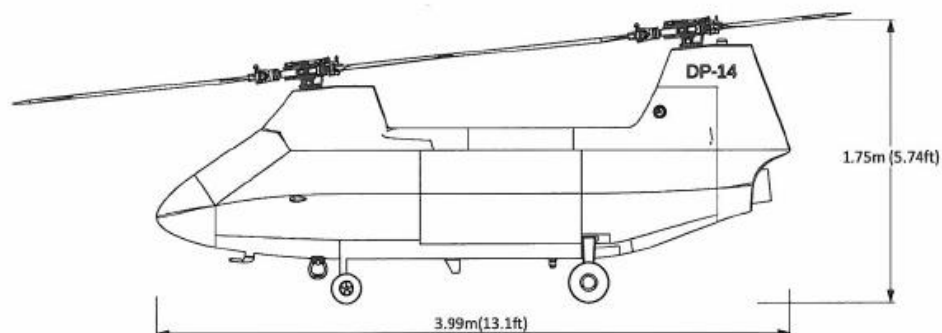


Figure 5. DP-14 Model Rotorcraft from Dragonfly Pictures, Inc.



Figure 6. Unmanned Tandem-Rotor Precision-Spray Aircraft

The systems on the UA are typical of those used on midsize UAS they have limited size, weight, and power (SWAP). The UA is equipped with onboard sensors and an autopilot system that allow it to operate semi-autonomously. These onboard elements enable onboard position determination, onboard guidance computations, automatic stabilization, and fully automatic inner- and outer-loop vehicle control. Direct operator control of the vehicle is not available as a primary or backup control mode, but the operator can intervene via the activation of predetermined commands.

Automatic takeoff and landing (also referred to as launch and recovery) are required for all modes of operation. Automatic takeoffs include a departure from the location of engine start to the first waypoint that defines the commencement of the intended spray operation. Automatic landing will return the UA to the intended point of landing from the last waypoint of the flight plan. The UA uses a ground-based multi-lateration system (see Section 6.4) to determine position and recognizes position relative to pre-defined containment boundaries (see Section 6.5). The UA's control system automatically lands if impending violation of the containment boundary is detected. The spray system is also disabled during such contingency maneuvers to ensure that chemicals are not sprayed outside of the containment zone.

Flight path control is fully automatic in accordance with a preloaded prescription spray map. During flight, the UA uses direct height measurement from a radar or laser altimeter to provide precise altitude control above the crops in the field. The direct height measurement is bank angle compensated to ensure accurate control of altitude during normal maneuvering. The UA includes a backup barometric altimeter for contingency management of altitude. The barometric setting for the backup altimeter is set prior to flight and updated between flights.

The UA does not carry a transponder, but a low-cost automatic dependent surveillance-broadcast (ADS-B)-out unit may be incorporated to provide VFR traffic data to other aircraft (if permitted by SWAP limitations and cost). Aircraft position and state data is provided to the ground control station by datalink radios operating on frequencies approved for UAS operations or on frequencies approved for commercial or farm use, as appropriate. All operations are conducted within RLOS and most operations conducted within VLOS. If operations are conducted close to an airport with an operating control tower or other FAA facility, the ground control station will incorporate aviation band radios to maintain contact with the proximate facilities.

The UA design includes attributes to minimize the possibility of explosion or structural failure that releases high-energy parts. This includes the design, fabrication, and installation of fittings, valves, filler

tubes, drains, vents, and supporting structure for the fuel, oil, and other systems containing flammable fluids. The turbine engine installation includes containment rings around the turbine and compressor sections to ensure that an engine structural failure does not allow high-energy parts to escape from the engine compartment. The vehicle design includes a clutch or similar device that allows the rotor system to freewheel in the event of engine failure or seizure. Based on these design features, certification of the engine under Part 33 of 14 CFR may not be required.

An onboard vehicle health management system is incorporated into the design to automatically monitor safety-critical components and command a contingency landing in the event of a failure. The health monitor may also activate contingency maneuvers such as a return to takeoff location for less critical failures. The pilot is alerted over the datalink of any health monitor interventions. The pilot may also activate similar preprogrammed interventions via datalink if there are external indications of a non-normal state (e.g., smoke) that has not been detected onboard.

In the event of an engine failure or activation of the fuel cutoff valve associated with the contingency systems at very low altitudes, the vehicle is designed to descend slowly from spray height, settling to the surface in such a manner that the rotors will not impact the ground or any parts of the vehicle. If the vehicle must ascend above spray height, the autopilot is programmed to maintain a forward velocity proportional to altitude consistent with the height-velocity (“deadman’s”) curve [32] established during flight testing. This ensures that the vehicle can safely land from any normal operational condition and the vehicle and all of its parts will stay within the containment zone.

## **6.2. Ground Control Station**

The ground control station is integral to the ground support vehicles that transport, launch, and recover the UA. The ground control station is portable so that its location can be optimized with respect to VLOS considerations, radio coverage, operational efficiency, and protection by the containment system. The ground control station incorporates man-portable displays and controls that allow the pilot in command to directly observe the operation of the UA from takeoff through landing when operating within VLOS. When operating beyond VLOS (BVLOS), the ground control station includes an enclosure that provides controlled lighting, weather protection, and additional displays as required. The enclosed ground control station is designed to be compliant with the Occupational Safety and Health Administration (OSHA) requirements that provide for the safety of its occupants.

The ground control station supports the following:

- downloading and converting the prescription map to an aerial application overlay on a geospatial database such as Google Earth,
- converting the geospatial overlay into a series of waypoints that can serve as the basis for a lateral navigation plan for loading into the UA’s onboard flight management system/autopilot,
- associating spray commands with each waypoint,
- entering “no-fly” regions into the database or flight plan to protect known obstacles or human habitation areas within the operational zone,
- assigning precision altitudes to the waypoint plan to adjust spray distribution patterns or provide vertical separation from small obstacles,
- running the flight plan in simulation mode to verify the viability of the plan
- loading the tested flight plan into the UA’s computers and verifying proper loading,
- running diagnostic vehicle tests to validate flight readiness,
- communicating with visual observers (where utilized) dispatched to key locations to clear the airspace and the containment zone for the flight,
- activating and monitoring the containment and active obstacle detection systems,

- monitoring the progress of the flight visually or electronically, as needed for the operation being conducted,
- sending specific commands to the UA that bring it into a safe state (e.g., low hover, land, or return to base) if non-normal conditions exist that are not automatically detected and compensated,
- monitoring critical on-board systems of the UA or monitoring commands from the onboard health monitoring system, and
- bringing operations to a safe conclusion in the event of a power loss at the ground control station.

### **6.3. Command and Control Datalinks**

The C2 datalinks operate in approved spectrum allocated for UAS conducting commercial agricultural operations. Operational frequencies come from spectrum designated for farm operations, UAS operations, or other relevant spectrum. Receivers and transmitters are tunable to allow for changing frequency requirements in different areas. Bandwidth requirements are minimized by the highly automated design of the vehicle.

The datalink operates at a power level appropriate to the range requirements for each mission. The datalink is frequency agile to minimize the possible effects of electromagnetic interference and provide link security. While operations may be conducted BVLOS, they will not be conducted beyond RLOS to avoid the latency and dropout issues associated with satellite relay systems. RLOS covers quarter-section fields at the low flight altitudes embodied in this ConOps. Signal strength is tested at startup for each operation.

The UAS will have at least one C2 link for safety-critical information such as commands required for contingency maneuvers. Other datalinks may be used for telemetry and other non-safety-critical information. The vehicle incorporates automated contingency actions to execute for lost-link events.

### **6.4. Positioning System**

To achieve the navigation accuracy required by the ConOps, the onboard GPSs are designed to use proprietary differential signals from a dedicated, high accuracy, ground-based receiver such as those typically used in survey applications. If a differential system is already available for use with ground-based farm equipment, that system may also be used for the UA provided the reliability and design of the ground system meets the requirements of the type certificate. A real-time kinematic GPS is another alternative that can be used to provide the required level of accuracy.

Wide area augmentation system (WAAS)-capable receivers may be used when the required precision for a given application job is around 3 meters or greater. The service provider will carry out preflight surveys to ensure the availability of WAAS signals.

The differential GPS is monitored from the ground control station and onboard the UA, so that operations may be terminated if GPS signals are lost or the required level of accuracy is not available.

### **6.5. Assured Containment System**

An assured containment system is a localization system, independent of the autopilot, that acts to keep the UA within given bounds. A containment system comprises sensors to determine the vehicle state information, decision logic to detect an anticipated breach of containment, and the means to control the breach of containment (e.g., flight termination). The *assured* part of the concept comes from design attributes intended to ensure that the UA will remain in a specified area in the presence of common vehicle, autopilot, sensor and actuator failures. The UA design includes an assured containment system in part to offset reliability requirements on the UA autopilot. As posited here, an assured containment

system can be realized by a smaller set of functions than a typical autopilot provides. Keeping the system simple facilitates certification-quality safety arguments.

An assured containment system is not currently available on the market, though one could be developed using existing technology. For this application, the containment system would incorporate an independent system for determining the location of the UA based on three or more low power transmitters prepositioned to provide good multi-lateration geometry over the operational area. The UA would contain two receiver/processors preloaded with lateral and vertical containment boundaries, including buffers as necessary to allow for operation at and near boundaries. The receiver/processors would receive signals from antennas on the vehicle and continuously triangulate to determine current lateral and vertical position. The current position would be differentiated to determine a velocity vector. The position and velocity data would be processed to determine a projected time to crossing of the boundary. If the UA does not take action to adjust its path or speed to stay within the boundaries, the containment system would force the vehicle to land by closing an emergency fuel shutoff valve. The valve would operate independently of the ship's systems, autopilot, and primary and backup power sources. An activation signal would be sent to the operator via datalink and the operator would back up the automatic action with a command to close the normal fuel shutoff valve.

A number of alternative system designs can provide independent positioning capability: eLoran, radars, acoustic systems, and people who serve as spotters. An automated system was proposed to support BVLOS operations. Ideally, automation reduces staffing requirements and error from fallible human judgments of positions, speeds and boundary locations.

## **6.6. Ground-Based Detect and Avoid (GBDAA) System**

Some capability to detect and avoid other aircraft is needed despite the fact that most aerial application will occur just above crop height. During VLOS operations, the pilot in command and visual observers can provide the detect and avoid function. To support BVLOS operations, a system that can detect aircraft by non-visual means will be needed. An automated detect and avoid system is not currently available on the market, though one could be developed using existing technology. One possible option is a system that includes a portable ground or radar-based detect and avoid system to provide the pilot in command with a warning if another aircraft approaches the containment area. Upon notification of an intruder, a signal would be sent to the UA automatically or by the pilot in command (or both) that initiates a contingency response such as an immediate landing or low hover. A GBDAA system could be reset remotely by the pilot in command to resume UA operations once the hazard has passed. The GBDAA system would only be required to detect intruder aircraft, not compute avoidance maneuvers. For the ConOps, the avoidance maneuver is a single pre-programmed response that can be initiated by a single command from the ground control station.

A GBDAA system might use a variety of sensors such as acoustic detectors and various forms of radar. A particularly interesting option is a commercial-off-the-shelf marine radar modified to detect low flying aircraft at a minimum range of 5 miles. This range requirement supports a buffer around the planned area of operations of about 3 miles, assuming the radar is centrally located. This range provides sufficient time for the UA to execute a contingency action. The system could operate in the background and send automatic commands to the UA and alerts to the pilot in command when a conflict is detected. The system would not be capable of providing resolution maneuvers but only detection alerts.

## **6.7. Active Obstacle Avoidance System**

The primary responsibility for avoiding known obstacles (e.g., barns or silos in the field) is functionally allocated to the onboard precision navigation system. The locations and boundaries of known obstacles

are determined during pre-mission planning and entered into the UA flight management system. The flight path of the UA is compared to these locations and adjusted to provide clearance from them.

To avoid unknown or dynamic obstacles as required by the ConOps, the pilot in command and visual observers can provide the detect and avoid function during VLOS operations. For BVLOS operation, an active onboard obstacle detection and avoidance system would need to be included in the system design. Such a system is not currently available on the market, though one could be developed using lidar, acoustics, radar, or other technologies. For this application, the hypothetical system could use an adaptation of an automotive camera-based pattern recognition system such as those produced by Mobileye, Inc. [33] to keep cost and power requirements low. When an obstacle is detected, the avoidance system would send a command to the autopilot and thrust systems to execute a contingency landing and power down the vehicle. After any contingency landing, a crew member would be required to clear the hazard and reset the system.

## **6.8. Payload and Spray Equipment**

The hypothetical system design assumes that the agricultural spray system is a permanent part of the vehicle and, as such, the certification of the spray system is included in the vehicle type certification. Agricultural requirements established by 14CFR Part 137 are not considered in this assessment.

The hypothetical system is designed to dispense liquid chemicals using a pressurized spray system. The available fuel and payload tankage is such that full loads of both will exceed maximum gross weight limitations. Thus, the amounts of fuel and chemical payload carried are chosen such that the vehicle's mission endurance in fuel and payload are proportionate for each mission. The design and operation of the vehicle leaves adequate fuel reserves to return to the landing location any time during the mission with adequate margins of safety.

The vehicle structure, control systems, and spray system design take into consideration the stiffness of the spray booms and takeoff, landing, and maneuvering requirements. Height and bank angle compensation, or coordination, is provided to ensure that the spray system does not contact the ground during low altitude spraying just above the crop canopy. Spraying at low altitude is a necessary design requirement to minimize overspray resulting from wind and rotor wash entrainment.

As a safety consideration, the spray system design includes two methods of shutting off the spray. The primary shutoff is operated by the normal spray system and allows activation and deactivation of all or individual nozzles according to the requirements of the prescription map. A second independent shutoff system is capable of emergency shut off of all spray regardless of the status of the primary system. Such a system allows positive shut off by on-board or off-board activation of the containment or other contingency systems.

## **6.9. Support Equipment**

The vehicle design includes support vehicles that are needed for transportation, launch, servicing, and recovery of the UA, as well as providing support for the agricultural service (e.g., loading chemicals). The specimen configuration includes one vehicle capable of transporting the UAS over roads and highways in the U.S., including secondary roads typically found in rural farm areas. The vehicle design complies with all federal and state motor vehicle regulations regarding weight and size and incorporates required safety features. The transport vehicle also incorporates leveling and rotor wash protection features that allow it to serve as the initial launch and final recovery platform. A separate vehicle with off-road capabilities provides a capability to retrieve the UA from a field in the event of a contingency landing that does not allow continued flight. This vehicle is also used to deploy observers and any necessary field equipment. Another vehicle carries fuel, oil, and chemical supplies to allow field replenishment of the vehicle and

spray system. This vehicle incorporates safety features for fire and explosion suppression consistent with the liquids being carried.



## 7. Conclusions

This report provides an example of the first major product in a civil aircraft's type certification process, namely, the type certification basis—in this case, for an unmanned rotorcraft performing an aerial application operation. The purpose of this effort is to determine, in a general sense, plausible airworthiness requirements for an unmanned rotorcraft in a low-risk operation. Due to the narrow scope of this effort—a specific UA performing a specific type of operation—this work does not provide definitive information applicable to all UAS in all possible operational contexts. The narrow scope, however, allows for serious, in-depth consideration of real-world concerns, peculiarities, and special mitigations for a particular UA and operation. If a larger variety of vehicles had been chosen or a wider range of operations, then this work would either have been either too general to be useful or, since all potential hazards must be mitigated, too restrictive to be a practical/economic operation. The intent was to suggest a strawman set of design and performance requirements, based on Part 27, to use as a starting point for establishing a reasonable certification basis for similar UA performing similar low-risk operations. Approximately 25% of the regulations in Part 27 were directly applicable to this type certification basis without significant modification. In total, approximately 55% of the regulations in Part 27 were useful in addressing primary hazards associated with the UAS and its operation.

One key observation from this activity is that there is a fundamental connection between the aircraft, its ConOps, and the safety of the system. Regulatory requirements for most CPA are developed implicitly around an operational model of transporting people and cargo from one point to another. No specific documentation of that operation is required in the aircraft certification process. Many UAS operations do not fit the CPA transportation model. UAS operations for tasks like surveillance, inspection, and agriculture, involve taking off and landing from the same point, while other UAS operations involve significant time loitering in a designated area—all different from the transportation model. Different operational models have the potential to introduce different hazards that affect requirements for UA systems and equipment. By providing details about the operation, special considerations inherent to the safety of the UA are revealed. In this case study, for example, operation within a defined geospatial containment volume that contains no people is a special consideration that significantly impacts design and performance considerations. Other operations may have different hazards, necessitating different safety considerations. In any case, the operation and operational environment have a non-trivial effect on design requirements. So, for UAS, documentation of the ConOps may become an essential artifact for type certification.

Another key observation of this work is that one hazard may mask a secondary hazard. Consequently, efforts to mitigate a hazard must ensure that secondary hazards are also mitigated. For example, a crash of an unmanned aerial applicator, in a field cleared of people, would not be considered by most to be a safety concern. Such a crash would have economic implications, but no direct safety implications. Further consideration of such an event, however, resulted in identifying hazards related to (a) detecting people who may enter the field during the operation and (b) release of high-energy parts that could exit the containment area. Hazards, especially those relevant to people on the ground, might be different from those on a typical CPA project, and might not be obvious at first glance.

The final key observation is that hazards in UAS might be best identified by considering ways in which the public (i.e., people on the ground or in other aircraft) might be injured. The transitive notion of safety, that is, the idea that protecting the aircraft will, in turn, protect the public, is neither necessary nor sufficient for many UAS and their intended operations. For agricultural operations and perhaps many other UAS operations, the regulations need only be concerned with protecting the public. For many UAS operational models, economic considerations and insurance, not airworthiness regulation, will become primary drivers for requirements to protect the UA from hull loss.

Further work in the form of additional case studies and operational experience is needed to substantiate or refute these observations and provide data needed to inform the development of regulatory policy and standards for different UAS types and operations.

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## Appendix. Rationale for the Mock Type Certification Basis

Just as the intent behind a regulation is not always obvious, neither is the reasoning for why a requirement might or might not be considered applicable in a different context. The rationale provided in Table A.1 attempts to provide insight into the assessment of each of the Part 27 requirements for applicability to the AgR-1 and inclusion in the mock type certification basis. Table A-1 lists each of the Part 27 requirements and indicates whether each requirement is included in the mock type certification basis, excluded from the mock type certification basis, or “rolled up” into one of the supplemental issue papers (CMS, SI, or PPS). For requirements included in the mock type certification basis, the text of the proposed requirement is given, along with rationale for why it is included or modified. Additions to the original text are indicated in blue italic face and deletions are indicated by striking through the text. For requirements that are rolled up, a brief summary of the requirement is given, along with rationale for why it has been rolled up.

The rationale, by its nature, is subjective. The intent is to offer a starting point for discussing potential changes to existing regulations to better define the desired safety characteristics of a UAS and its ConOps. A few common themes appear in the rationale, including the following reasons for excluding a requirement from the type certification basis:

- (1) Out of vehicle scope. This means that the Part 27 requirement is intended for a rotorcraft whose characteristics are not consistent with those of the AgR-1, e.g., piston engines and multiple engines. Vehicles with tandem rotors and a single turbine engine and vehicles with a single rotor, a tail rotor, and a single turbine engine are in scope.
- (2) Out of ConOps scope. This means that the operational aspects specified in the Part 27 requirement are not relevant to the ConOps; e.g., icing conditions, lightning, operation beyond radio line-of-sight, presence of a manual reversion mode (e.g., stick-to-surface control), taxiing, and skis and floats.
- (3) Does not map to a hazard. This means that the Part 27 requirement is not directly relevant to a primary (catastrophic, hazardous, or major) hazard identified in the hazard analysis. For example, an event resulting in hull loss is not a hazard under the ConOps. There are, however, hazards associated with loss of rotor system integrity; e.g., shedding of high energy parts.
- (4) Not UAS relevant. This means that the Part 27 requirement is irrelevant to a UAS by the design or operational characteristics of unmanned vehicles. For example, requirements related to crew or occupant protection, such as seat belts, are not UAS relevant.
- (5) Secondary hazard. This means that the hazard that underlies the Part 27 requirement is relevant to the AgR-1 under its ConOps, but not to the same degree as for a Part 27 rotorcraft. For example, engine seizure is not catastrophic unless coupled with the failure of a disconnect device for the rotor system.
- (6) Mitigated by other regulation. For some systems (e.g., the rotor system) for the provision of a device to protect the system obviates the need for other regulations. For example, loss of fuel pressure causing engine flameout is not catastrophic even if a hull loss occurs as long as the device that disconnects the engine from the drive system protects the drive system integrity.

The rationale in Table A.1 is intentionally informal and uses a shorthand description of the common themes. The terms “crew” and “crewmember” used herein include pilots, sensor/payload operators, visual observers, and other persons as appropriate or required to ensure safe operation and maintenance of the aircraft

**Table A.1. Applicability of Part 27 Paragraphs to an Unmanned Aerial Applicator**

<b>Part 27 Paragraph</b>	<b>Action</b>	<b>Paragraph text or Summary Rationale for Action</b>
<b>Subpart A—General</b>		
§27.1 Applicability	Excluded	Summary: This paragraph describes the types of rotorcraft subject to Part 27. Rationale: Out of vehicle scope. Out of ConOps scope. The UAS and ConOps are different from conventional Part 27 rotorcraft.
§27.2 Special retroactive requirements	Excluded	Summary: This paragraph describes special considerations for (a) rotorcraft manufactured after Sept 16, 1992 related to seats and (b) type certified prior to October 18, 1999. Rationale: Not UAS relevant. The UAS will not need seats. Furthermore, any vehicle operating under the G-1U will be certified after October 18, 1999.
<b>Subpart B—Flight</b>		
<b>General</b>		
§27.21 Proof of compliance	Modified	<p>Each requirement of this <del>subpart</del> <i>G-1U Issue Paper</i> must be met. <del>at each appropriate combination of weight and center of gravity within the range of loading conditions for which certification is requested.</del> This must be shown (a) <del>By</del> tests upon a rotorcraft of the type for which certification is requested, or by calculations based on, and equal in accuracy to, the results of testing; and (b) <del>By systematic investigation of each required combination of weight and center of gravity if compliance cannot be reasonably inferred from combinations investigated.</del></p> <p>Rationale: “Subpart” was changed to “issue paper” because the original subpart, as a whole, is not applicable. The intent of this paragraph is that requirements included in the issue paper must be verified by testing and analysis of the rotorcraft as applicable. Only those loading conditions that could lead to loss of structural integrity of the rotor system are of concern. The requirement for test and/or analysis for all of the weight and center of gravity combinations called for in Part 27 was simplified because the unmanned rotorcraft has fewer loading conditions that are safety critical. Therefore, language requiring test and/or analysis at all weight/cg combinations was deleted. Furthermore, weight and center of gravity are not the only important parameters that may affect loading conditions. The applicant should determine which parameters, including weight and center of gravity, are critical to structural integrity of the rotor system and demonstrate through test and analysis that the aircraft can handle these parameters with adequate safety margins. Weight and center of gravity are rolled up along with other critical parameters in separate issue papers for structural integrity and for controllability, maneuverability, and stability.</p>

§27.25 Weight limits	Rolled up to CMS(a) & SI	<p>Summary: This paragraph establishes requirements for determining maximum, minimum, and total weights including jettisonable payloads for manned helicopters.</p> <p>Rationale: Weight, weight distribution, and inflight changes in weight can affect vehicle moments of inertia and control margins, affecting CMS. For a single purpose UAS design, detailed establishment of all of the weights called for in Part 27 might be unnecessary. The CMS rollup requires that the applicant determine which weight and loading conditions are critical to vehicle CMS and to demonstrate that the vehicle control system can handle these weights with adequate safety margins.</p> <p>These weights also have a direct effect on structural strength requirements for the rotor system, the drive system, and supporting structure. The SI rollup requires that the applicant determine which weight and loading conditions are critical to vehicle structural requirements, affecting rotor system integrity, and demonstrate that the vehicle design and fabrication can handle these weights with adequate safety margins.</p>
§27.27 Center of gravity limits	Rolled up to CMS(a) and SI	<p>Summary: This paragraph requires the applicant to establish various centers of gravity, especially at the extremes (forward, aft, lateral).</p> <p>Rationale: The requirements of this paragraph are reasonable for a UAS design in a restricted operational context. However, because the requirements are tied to the weights established under §27.25, this paragraph was rolled up with §27.25. The generalized requirement is for the applicant to establish which center of gravity limits are critical and ensure that the vehicle is safely controllable and maneuverable for this range of values.</p> <p>Because the loading on each rotor of a tandem rotor design is affected by center of gravity locations and the center of gravity is generally related to the weights established under §27.25, a generalized requirement was included in the SI rollup for the applicant to establish which center of gravity limits are critical and ensure that the vehicle design provides adequate safety margins for this range of values.</p>
§27.29 Empty weight and corresponding center of gravity	Excluded	<p>Summary: This paragraph requires establishing empty weight and center of gravity used for stability analysis.</p> <p>Rationale: Does not map to a hazard. Loss of the vehicle within containment is not hazardous.</p>
§27.31 Removable ballast	Excluded	<p>Summary: This paragraph allows the use of removable ballast to help with center of gravity</p> <p>Rationale: Out of vehicle scope.</p>
§27.33 Main rotor speed and pitch limits	Rolled up to CMS(a) and SI	<p>Summary: This paragraph requires the applicant to establish main rotor speed and pitch limits used in determining centripetal, bending, and other critical loads applied to the rotors.</p> <p>Rationale: Main rotor speed and pitch limits relate primarily to structural integrity requirements of the rotor system and are rolled up in the issue paper on structural integrity. However, main rotor speed and pitch limits can also affect CMS considerations at limiting conditions, such as at max gross weights, takeoffs and landings at max slope limits, and at the never exceed speed (<math>V_{ne}</math>). This paragraph was rolled up into the CMS issue paper to require the applicant to consider these factors in designing the vehicle control and stabilizations systems.</p>
<b>Performance</b>		
§27.45 General	Excluded	<p>Summary: This paragraph prescribes how performance requirements are to be interpreted.</p> <p>Rationale: Does not map to a hazard. Not UAS relevant.</p>

§27.49 Performance at minimum operating speed	Excluded	Summary: This paragraph requires an applicant to determine performance at minimum operating speed. Rationale: Out of ConOps scope. Does not map to a hazard.
§27.51 Takeoff	Rolled up to CMS(a) and SI	Summary: This paragraph establishes minimum requirements for controllability and performance of the vehicle during takeoff with critical values of weight and center of gravity. Rationale: While the controllability requirement is stated in terms of pilot skill requirements, that are not applicable for the UAS, the requirement that the takeoff not require exceptionally favorable conditions is applicable to the UAS autopilot design. Therefore this requirement was included in the rollup. Subparagraph (b) that requires that the vehicle be capable of a safe landing following an engine failure during the takeoff profile also was deemed applicable but only where the inability to land safely represents a risk to persons or property on the ground. The rollup includes language that makes clear that requirements such as this paragraph are only applicable under some circumstances, thus opening the door for operational or other mitigations to the hazards to persons and property on the ground.
§27.65 Climb: all engines operating	Excluded	Summary: This paragraph requires an applicant to establish the steady rate of climb under various conditions. Rationale: Does not map to a hazard. Note: Requirements for avoiding obstacles are in the Detect & Avoid Dynamic Obstacles issue paper included in the G-1U.
§27.67 Climb: one engine inoperative	Excluded	Summary: This paragraph, applicable to multiengine rotorcraft, requires establishing steady rate of climb with one engine out. Rationale: Out of vehicle scope.
§27.71 Autorotation performance	Excluded	Summary: This requires the establishment of the best angle of glide and minimum rate of sink speeds in autorotation. Rationale: Out of ConOps scope. Does not map to a hazard.
§27.75 Landing	Rolled up to CMS(a) and SI	Summary: This paragraph, similar in intent to paragraph §27.51, requires the vehicle to be capable of being landed smoothly without exceptional pilot skill or exceptionally favorable conditions during both a normal approach and an autorotative approach. Rationale: Using the same logic as the takeoff case, the pilot skill requirement does not apply since there is no direct inner loop control by a pilot, but the requirement that a smooth landing be made without exceptionally favorable conditions may be directly applicable to the autopilot design. The general sense of the paragraph was included in the CMS rollup.
§27.87 Height-speed envelope	Rolled up to CMS(a)	Summary: This paragraph requires that any combinations of height and forward speed for which a safe landing cannot be made must be established for the relevant power failure condition. This limiting condition is sometimes known as the “Dead Man’s Curve”. Rationale: Engine failure from a height/speed combination that does not allow a successful autorotation would likely result in destruction of the rotor system and release of high energy parts. This paragraph, especially (b)(1) which requires full autorotation for a single engine helicopter, was included in the rollup as one of the critical conditions that the applicant must identify and mitigate.



Flight Characteristics		
§27.141 General	Rolled up to CMS(a) and SI	<p>Summary: This paragraph requires that the vehicle be capable of maintaining any required flight condition and be able to transition smoothly between flight conditions without exceptional pilot skill and without danger of exceeding limiting load factors. A list of parameters for which critical conditions must be tested, including weights, center of gravity, altitudes, temperatures, engine failure conditions, etc., are specified.</p> <p>Rationale: While the exceptional piloting skill requirement would not be applicable to a vehicle with no provisions for inner loop pilot control, the same requirements would apply to the autopilot design and implementation. Subparagraph (c) also requires that the vehicle possess any required flight characteristic necessary for night or instrument flight, if certification for such conditions is requested. Since the ConOps includes night and limited visibility operations, this subparagraph was included in the CMS and SI rollups.</p>
§27.143 Controllability and maneuverability	Rolled up to CMS(a)	<p>Summary: This paragraph requires that the vehicle be safely controllable and maneuverable for a specified set of normal operations, such as takeoff, landing, and steady flight, and for non-normal conditions, such as autorotation (if implemented) and power-on recoveries. The paragraph also specifies that adequate control margins exist at <math>V_{ne}</math> for critical values of relevant parameters. The paragraph further specifies wind and density altitudes for which the vehicle must be safely controllable and maneuverable and critical values of other parameters.</p> <p>Rationale: Under the ConOps, neither <math>V_{ne}</math>, nor 7000 ft will likely be reached. However, the general requirement that the vehicle be safely controllable and maneuverable over a relevant set of conditions with critical values of other parameters, such as weight, center of gravity, rotor speed, and power condition would be a necessary precondition for maintaining rotor system integrity.</p>
§27.151 Flight controls	Rolled up to CMS(a)	<p>Summary: This paragraph sets limits on breakout forces, friction, and preloads, and requires that the control system be designed and installed such that the vehicle responds directly and smoothly to control system inputs.</p> <p>Rationale: Although the UAS has no inner-loop control by a human operator, this requirement may be applicable to the autopilot design and was included in CMS(a).</p>
§27.161 Trim control	Excluded	<p>Summary: This paragraph requires that the rotorcraft be trimmable for the longitudinal, lateral, and collective controls.</p> <p>Rationale: Out of vehicle scope. Since the AgR-1 inner loop is controlled exclusively by an autopilot, trim forces are not relevant.</p>
§27.171 Stability: general	Excluded	<p>Summary: This paragraph requires an applicant to consider pilot fatigue and strain in designing stability characteristics.</p> <p>Rationale: Not UAS relevant, because the remote pilot would not be subject to stability characteristics.</p>
§27.173 Static longitudinal stability	Rolled up to CMS(a)	<p>Summary: This paragraph specifies requirements for design and testing for static longitudinal stability throughout the full range of altitude allowed under the rotorcraft's certification.</p> <p>Rationale: There should be no requirements on static stability for a completely automatic control system. The requirement for testing across the full range of altitude is overly burdensome. However, this requirement may be applicable to the autopilot design and testing should be considered with §27.175 and §27.177 for CMS.</p>

§27.175 Demonstration of static longitudinal stability	Rolled up to CMS(a)	Summary: This paragraph specifies requirements for testing static longitudinal stability in different phases of flight, under different conditions. Rationale: Same logic as §27.151. There should be no requirements on static stability for a completely automatic control system. However, this requirement may be applicable to the autopilot design and demonstration and considered for CMS.	
§27.177 Static directional stability	Rolled up to CMS(a)	Summary: This paragraph relates to sense and direction of motion of the vehicle in response to movement of the directional controls. Rationale: There should be no requirements on static directional stability for a completely automatic control system. However, this requirement may be applicable to the autopilot design and considered for CMS.	
Ground and Water Handling Characteristics			
§27.231 General	Rolled up to CMS(a)	Summary: This paragraph relates primarily to “handling characteristics.” Most handling characteristics are pilot perceptions of the controllability and maneuverability of the vehicle. Rationale: Handling characteristics are not applicable to a UAS that is not under direct control of a human operator. However, the paragraph also states that the vehicle must be free from uncontrollable tendencies in any condition expected in operation. This may be a relevant requirement for protecting rotor system integrity and was included in the rollup.	
§27.235 Taxiing condition	Excluded	Summary: This paragraphs deals with withstanding loads related to taxiing the rotorcraft. Rationale: Out of ConOps scope.	
§27.239 Spray characteristics	Excluded	Summary: This paragraph deals with mitigating the possibility of spray (from water operation) that can obscure a pilot’s vision. Rationale: Out of ConOps scope.	
§27.241 Ground resonance	As is	The rotorcraft may have no dangerous tendency to oscillate on the ground with the rotor turning.	Rationale: This paragraph was included because of potential hazards from ground resonance to the (ground) crew in proximity during takeoff and landing.
Miscellaneous Flight Requirements			
§27.251 Vibration	Rolled up to SI	Summary: This paragraph requires that the vehicle be free of excessive vibration for applicable speed and power conditions. Rationale: While vibration can affect structural strength and fatigue requirements the requirement is of interest only as it might affect rotor system integrity. Since the relationship between vibration and rotor system structural integrity might have many dimensions, including inspection types and frequencies, lifetime limits on parts, etc., this requirement would best be addressed as a part of the overall considerations to ensure rotor system integrity.	
Subpart C—Strength Requirements			
General			
§27.301 Loads	Excluded	Summary: This paragraph requires loads affecting structural strength requirements to be in equilibrium with inertia forces. Rationale: Does not map to a hazard.	
§27.303 Factor of safety	Excluded	Summary: This paragraph specifies the factor of safety to be used with loads. Rationale: Does not map to a hazard. The requirement in §27.602 addresses design requirements for critical parts.	

§27.305 Strength and deformation	Excluded	Summary: This paragraph requires tests to ensure that structure does not permanently deform or fail under load conditions. Rationale: Does not map to a hazard.
§27.307 Proof of structure	Rolled up to CMS(b) & SI	Summary: This paragraph requires that an applicant show by analysis or other tests that the structure meets the strength and deformation requirements of the subpart. Rationale: Since the requirements specifically include limit load tests of the control system including control surfaces, this paragraph was rolled up into the CMS issue paper.
§27.309 Design limitations	Rolled up to CMS(b) and SI	Summary: This paragraph sets values for parameters considered critical for showing compliance with the structural requirements. Rationale: Parameters such as rotor speed and forward, rearward, and sideward speeds, affect the control system requirements and should be considered in the rolled up CMS requirements. The roll-up allows the applicant to establish which parameters are critical, as opposed to specifying them in the requirement.
<b>Flight Loads</b>		
§27.321 General	Rolled up to CMS(a) and SI	Summary: This paragraph specifies assumptions about flight load factors and provides general guidance for complying with flight load requirements in Part 27. Rationale: Since load factors are induced by control movements, the general requirement to address flight loads with respect to controllability and structural integrity should be considered. This may drive design requirements on the autopilot. This requirement was included in the CMS and SI rollups.
§27.337 Limit maneuvering load factor	Rolled up to CMS(a) and SI	Summary: This paragraph specifies a range of limiting load factors in terms of the probability of being exceeded as shown by analysis and flight tests. Rationale: Since load factors are induced by control movements this may be considered as a design requirement on the autopilot and thus was included in the rollups.
§27.339 Resultant limit maneuvering loads.	Excluded	Summary: This paragraph describes assumptions about how loads from limit maneuvering load factors should act and defines a rotor tip speed ratio. Rationale: This paragraph provides supporting information for §27.337. Because §27.337 may be interpreted or applied in different ways for UAS, this paragraph is not necessary for the type certification basis.
§27.341 Gust loads	Excluded	Summary: This paragraph requires rotorcraft to withstand loads from vertical wind gusts. Rationale: Out of ConOps scope. Secondary hazard.
§27.351 Yawing conditions	Excluded	Summary: This paragraph specifies requirements for designing for loads under various conditions in unaccelerated flight with zero and maximum achievable yaw. Rationale: Out of ConOps scope. Secondary hazard.
§27.361 Engine torque	Excluded	Summary: This paragraph specifies minimum values for limit torque for different engine types to protect the engine from mechanical overload. Rationale: Secondary hazard.
<b>Control Surface and System Loads</b>		
§27.391 General	Rolled up to CMS(b) & SI	Summary: This paragraph establishes what elements of the control system fall under subsequent paragraphs which specify design requirements. Rationale: The elements specified (auxiliary rotors, fixed or movable control surfaces, and each system operating any flight control) might apply in some form and thus were rolled up to CMS(b) and SI.

§27.395 Control system	Rolled up to CMS(b)	<p>Summary: This paragraph establishes the maximum loads that the control system must be designed to handle.</p> <p>Rationale: The requirements are expressed primarily in terms of pilot-applied loads, which would not be relevant but the requirements also covers loads from power actuators and these are relevant. The paragraph also specifies other conditions that must be considered in control system design. These include friction, jamming, fatigue, inertias, and gusts, which would be relevant to maintaining the integrity of the rotor control system. This paragraph was rolled up into the CMS Issue Paper to ensure that the applicant addresses power actuator loads and the various other design requirements that would ensure rotor system integrity.</p>	
§27.397 Limit pilot forces and torques	Excluded	<p>Summary: This paragraph specifies limit pilot forces.</p> <p>Rationale: Not UAS relevant.</p>	
§27.399 Dual control system	Excluded	<p>Summary: This paragraph places requirements on dual flight control systems to withstand loads associated with specified pilot forces.</p> <p>Rationale: Not UAS relevant.</p>	
§27.411 Ground clearance: tail rotor guard	Modified	<p><i>For rotorcraft with tail rotors:</i></p> <p>(a) It must be impossible for the tail rotor to contact the landing surface during a normal landing.</p> <p>(b) If a tail rotor guard is required to show compliance with paragraph (a) of this section—</p> <p>(1) Suitable design loads must be established for the guard; and</p> <p>(2) The guard and its supporting structure must be designed to withstand those loads.</p>	<p>Rationale: This paragraph was modified to increase the applicability of the type certification basis to non-tandem rotorcraft. Impact of the tail rotor with the ground may lead to loss of integrity of the tail rotor and result in high energy parts being ejected from the containment zone.</p> <p>Additionally, the crew is in proximity to the rotorcraft during landing. Thus a loss of rotor hub integrity may result in crew impact from any ejected parts (high energy or not). Furthermore, since there is likely a physical connection between the tail rotor and the main rotor, damage to the tail rotor might cause damage to the main rotor, leading to a further ejection of high energy parts.</p>
§27.427 Unsymmetrical loads	Modified	<p><i>For rotorcraft with tail rotors:</i></p> <p>(a) Horizontal tail surfaces and their supporting structure must be designed for unsymmetrical loads arising from yawing and rotor wake effects in combination with the prescribed flight conditions.</p> <p>(b) To meet the design criteria of paragraph (a) of this section, in the absence of more rational data, both of the following must be met:</p> <p>(1) One hundred percent of the maximum loading from the symmetrical flight conditions acts on the surface on one side of the plane of symmetry, and no loading acts on the other side.</p> <p>(2) Fifty percent of the maximum loading from the symmetrical flight conditions acts</p>	<p>Rationale: This paragraph was modified to increase the applicability of the type certification basis to non-tandem rotorcraft.</p> <p>(a) Given the critical loading profile determined in §27.21 and/or CMS(a) and (b), a demonstration of structural integrity of the rotor hub under maximal loading applied at both full and half moments of inertia for the rotor disc is regarded as being sufficient to prevent the frequent ejection of high energy parts from the containment area under asymmetric loading conditions.</p> <p>(b) Given the critical loading profile determined in §27.21 and/or CMS(a) and (b), empennage tail rotor surfaces must</p>

		on the surface on each side of the plane of symmetry but in opposite directions. (c) For empennage arrangements where the horizontal tail surfaces are supported by the vertical tail surfaces, the vertical tail surfaces and supporting structure must be designed for the combined vertical and horizontal surface loads resulting from each prescribed flight condition, considered separately. The flight conditions must be selected so the maximum design loads are obtained on each surface. In the absence of more rational data, the unsymmetrical horizontal tail surface loading distributions described in this section must be assumed.	further assure structural rotor hub integrity under combined longitudinal and lateral maximal loading profiles for each critical flight condition, unless it can be demonstrated that lower values are only ever achieved. This will sufficiently mitigate the ejection of high energy parts from the containment area under maximal lateral and longitudinal loading conditions.
<b>Ground Loads</b>			
§27.471 General	Excluded	Summary: This paragraph provides general guidance for what is meant by limit ground loads (external loads), and guidance for selecting critical centers of gravity with respect to maximum load on the landing gear. Rationale: Secondary hazard.	
§27.473 Ground loading conditions and assumptions	Excluded	Summary: This paragraph sets requirements for establishing design maximum weight used in determining strength requirements for ground loads. Rationale: Secondary hazard.	
§27.475 Tires and shock absorbers	Excluded	Summary: This paragraph states assumptions on tire and shock absorber positions for landing, to be used in determining strength requirements. Rationale: Secondary hazard.	
§27.477 Landing gear arrangement	Excluded	Summary: This paragraph specifies how the wheels of a landing gear should be arranged with respect to the center of gravity for paragraphs related to taxiing and some load characteristics. Rationale: Secondary hazard.	
§27.479 Level landing conditions	Excluded	Summary: This paragraph specifies landing load conditions to be considered in establishing strength requirements. Rationale: Secondary hazard.	
§27.481 Tail-down landing conditions	Excluded	Summary: This paragraph specifies tail down landing conditions to be considered in establishing strength requirements. Rationale: Secondary hazard.	
§27.483 One-wheel landing conditions	Excluded	Summary: This paragraph specifies one wheel landing conditions to be considered in establishing strength requirements. Rationale: Secondary hazard.	

§27.485 Lateral drift landing conditions	Excluded	Summary: This paragraph specifies lateral drift landing conditions to be considered in establishing strength requirements. Rationale: Secondary hazard.
§27.493 Braked roll conditions	Excluded	Summary: This paragraph specifies braked roll conditions to be considered in establishing strength requirements. Rationale: Secondary hazard.
§27.497 Ground loading conditions: landing gear with tail wheels	Excluded	Summary: This paragraph specifies ground loading conditions for rotorcraft with tail wheels. Rationale: Secondary hazard.
§27.501 Ground loading conditions: landing gear with skids	Excluded	Summary: This paragraph specifies ground loading conditions for rotorcraft with landing gear with skids. Rationale: Secondary hazard.
§27.505 Ski landing conditions	Excluded	Summary: This paragraph specifies ground loading conditions for rotorcraft with skis. Rationale: Out of ConOps scope.
<b>Water Loads</b>		
§27.521 Float landing conditions	Excluded	Summary: This paragraph specifies loading conditions for rotorcraft certificated for float operation. Rationale: Out of ConOps scope.
<b>Main Component Requirements</b>		
§27.547 Main rotor structure	Rolled up to SI	Summary: This paragraph specifies conditions and values for which each main rotor system must be designed. Rationale: The specific conditions and values should be screened with respect to the specific risks associated with an unmanned vehicle in an agricultural application in rural areas, especially given that the safety issue is limited to rotor system integrity under a very narrow set of operating conditions. Thus, the paragraph was relegated to the issue paper where critical conditions related to rotor system integrity could be substituted for the specific requirements of the paragraph.
§27.549 Fuselage, landing gear, and rotor pylon structures	Rolled up to SI	Summary: This paragraph specifies conditions and values for which the fuselage, landing gear, and rotor pylons must be designed by reference to numerous other paragraphs. Rationale: As in §27.547, Specific conditions and values should be screened with respect to the specific risks associated with an unmanned vehicle in an agricultural application in rural areas, especially given that the safety issue is limited to rotor system integrity under a very narrow set of operating conditions. Thus, the paragraph, like §27.547, was relegated to the issue paper.

Emergency Landing Conditions			
§27.561 General	Excluded	Summary: This paragraph specifies load factors that must be considered in structural design to protect rotorcraft occupants during emergency landings. Rationale: Not UAS relevant. Does not map to a hazard.	
§27.562 Emergency landing dynamic conditions	Excluded	Summary: This paragraph specifies many factors related to occupants seats and restraints that must be considered in structural design to protect occupants during emergency landings. Rationale: Not UAS relevant. Does not map to a hazard.	
§27.563 Structural ditching provisions	Excluded	Summary: This paragraph describes factors that must be considered in structural design during emergency landings that take place in water (ditching). Rationale: Out of ConOps scope.	
Fatigue Evaluation			
§27.571 Fatigue evaluation of flight structure	Rolled up to SI	Summary: This paragraph establishes requirements for the elements of the flight structure that must be identified and evaluated with respect to fatigue considerations, including rotor system and drive components. The paragraph further specifies procedures and measurement techniques that must be used to determine loads and stresses and fatigue tolerances. Rationale: While fatigue considerations were considered important in ensuring the rotor system integrity, the specifics of this paragraph were considered too detailed to be applicable as written to an unmanned rotorcraft in a very limited operational circumstance. Thus, the requirements of the paragraph were rolled up to SI.	
§27.573 Damage Tolerance and Fatigue Evaluation of Composite Rotorcraft Structures	Rolled up to SI	Summary: This paragraph specifies requirements and methodology for evaluating composite rotorcraft structures for with damage tolerance standards. Rationale: The ConOps requires flying very low over crops. The possibility of entrainment of ground debris into the rotor wake and subsequent impingement on rotorcraft structure must be considered. The specifics of this paragraph were considered too detailed to be applicable as written to an unmanned rotorcraft in a very limited operational circumstance. Thus, the requirements of the paragraph were rolled up into the more general statement of requirements in the issue paper.	
Subpart D—Design and Construction			
General			
§27.601 Design	Modified	(a) The <del>UAS rotorcraft</del> may have no design features or details that experience has shown to be hazardous or <del>unreliable</del> . (b) <i>For each questionable design detail whose failure could adversely affect safety, the</i> suitability of each questionable design detail and part must be established by tests.	Rationale: The entire system (i.e., the GCS and other components, not just the UA) must be free from hazardous features and details. A feature is hazardous if, during operations as described in the ConOps, it could lead to death of serious injury of any person or lead to a large reduction in safety margin. UAS design details that may be deemed conventionally questionable, such as the unqualified use of commercial-off-the-shelf components, pedigreed sensors and actuators etc., must only be considered with respect to their safety effects.
§27.602 Critical Parts	Modified	(a) Critical part. A critical part is a part, the failure of which could have a catastrophic effect upon the <del>rotorcraft</del> <i>UAS</i> , and for which critical characteristics have been	Rationale: A critical part is one whose failure results in a catastrophic failure for the UAS. Critical parts might be found in the containment system, ground control

		identified which must be controlled to ensure the required level of integrity. (b) If the type design includes critical parts, a critical parts list shall be established. Procedures shall be established to define the critical design characteristics, identify processes that affect those characteristics, and identify the design change and process change controls necessary for showing compliance with the quality assurance requirements of part 21 of this chapter.	station, receivers, etc. A critical parts list should include those parts whose failure is considered catastrophic, for example because it would result in the ejection of high energy parts from containment area or a fly away event.
§27.603 Materials	As is	The suitability and durability of materials used for parts, the failure of which could adversely affect safety, must— (a) Be established on the basis of experience or tests; (b) Meet approved specifications that ensure their having the strength and other properties assumed in the design data; and (c) Take into account the effects of environmental conditions, such as temperature and humidity, expected in service.	Rationale: Only safety critical systems need to meet this standard (all other systems need not comply and/or degrade gracefully). The provision that this only applies “for parts, the failure of which could adversely affect safety” is part of the Part 27 text. This phrase is included elsewhere since it is particularly relevant to this G-1U issue paper.
§27.605 Fabrication methods	Rolled up to CMS(b) and SI	Summary: This paragraph relates primarily to production methods, requiring methods that produce consistently sound structures and a test program to substantiate those methods. Rationale: This requirement is felt to be applicable to control system fabrication as well as other structures and so is included in the CMS rollup.	
§27.607 Fasteners	Rolled up to CMS(b) and SI	Summary: This paragraph establishes a requirement for locking devices for bolts, screws, nuts, pins, etc. used in any critical application that could jeopardize safe operations. Rationale: This paragraph was felt to be particularly applicable to control systems and so was rolled up into the CMS Issue Paper to force consideration of fasteners and their role in maintaining rotor system integrity.	
§27.609 Protection of structure	Modified	Each part of the structure, <i>whose failure could adversely affect safety</i> , must— (a) Be suitably protected against deterioration or loss of strength in service due to any cause, including— (1) Weathering; (2) Corrosion; and (3) Abrasion; and (b) Have provisions for ventilation and drainage where necessary to prevent the accumulation of corrosive, flammable, or noxious fluids.	Rationale: Only parts of the UAS structure that affect overall UAS system safety need meet this standard. However, parts of the system other than the UA might also affect safety and thus need to be considered. Safety considerations should include effects on the crew.
§27.610 Lightning and static electricity protection	Modified	<del>(a) The rotorcraft must be protected against catastrophic effects from lightning.</del> <del>(b) For metallic components, compliance with paragraph (a) of this section may be shown by—</del> <del>(1) Electrically bonding the components—</del>	Rationale: The ConOps does not allow for operations during conditions in which lightning occurs. (a-c) are not applicable as the lightning strike hazard is controlled operationally. (d) is mostly kept because details relevant



		<p><del>properly to the airframe; or</del>  <del>(2) Designing the components so that a strike will not endanger the rotorcraft.</del>  <del>(c) For nonmetallic components, compliance with paragraph (a) of this section may be shown by—</del>  <del>(1) Designing the components to minimize the effect of a strike; or</del>  <del>(2) Incorporating acceptable means of diverting the resulting electrical current so as not to endanger the rotorcraft.</del>  (d) The electrical bonding and protection against lightning and static electricity must—  (1) Minimize the accumulation of electrostatic charge;  (2) Minimize the risk of electric shock to crew, passengers, and service and maintenance personnel using normal precautions;  (3) Provide an electrical return path, under both normal and fault conditions, on rotorcraft having grounded electrical systems; and  (4) Reduce to an acceptable level the effects of static electricity on the functioning of essential electrical and electronic equipment.</p>	<p>to static electricity must be considered. Static electricity can electrocute a crewmember, so buildup must be mitigated. Neither lightning nor passengers need to be considered in (d).</p>
§27.611 Inspection provisions	Modified	<p>There must be means to allow the close examination of each part, <i>whose failure could adversely affect safety</i>, that requires—  (a) Recurring inspection;  (b) Adjustment for proper alignment and functioning; or  (c) Lubrication.</p>	<p>Rationale: Only safety-critical UAS parts need meet this standard (all other systems parts need not comply).</p>
§27.613 Material strength properties and design values	Rolled up to SI	<p>Summary: This paragraph specifies the materials and structural strength required for the vehicle.  Rationale: Material strength would likely be a factor in maintaining rotor system integrity. This paragraph was included in the SI roll-up.</p>	
§27.619 Special factors	Excluded	<p>Summary: This paragraph increases the factor of safety prescribed for bearings, fittings and castings for parts whose strength is variable, uncertain, or likely to deteriorate in service before normal replacement.  Rationale: Secondary hazard. The requirement in §27.602 addresses design requirements for critical parts.</p>	
§27.621 Casting factors	Rolled up to CMS(b) and SI	<p>Summary: This paragraph establishes manufacturing, inspection, and testing requirements for critical castings.  Rationale: Since any castings used in the control system would likely be critical to maintaining rotor system integrity, this paragraph was included in the CMS rollup.</p>	

§27.623 Bearing factors	Rolled up to CMS(b) and SI	<p>Summary: This paragraph specifies requirements for parts which have clearances and are subjected to pounding or vibration.</p> <p>Rationale: Rotorcraft are known to have such forces in their control systems and the bearing surfaces are also known to require specific clearances to control friction and binding in the system. The requirements of this paragraph were rolled up to CMS(b) and SI Issue Papers.</p>	
§27.625 Fitting factors	Rolled up to CMS(b) and SI	<p>Summary: This paragraph establishes a fitting factor of 1.15 and specifies the parts to which the factor applies if strength is not established in other acceptable ways.</p> <p>Rationale: Because the control system requires fitting of parts but the exact fitting factor may be different, this requirement was rolled up.</p>	
§27.629 Flutter	As Is	Each aerodynamic surface of the rotorcraft must be free from flutter under each appropriate speed and power condition.	Rationale: Flutter must not impact rotor system integrity.
Rotors			
§27.653 Pressure venting and drainage of rotor blades	Rolled up to SI	<p>Summary: This paragraph establishes requirements for rotor blade pressure relief and drainage for rotor blades that are not sealed.</p> <p>Rationale: This paragraph relates to rotor system integrity and could be relevant depending on rotor blade design.</p>	
§27.659 Mass balance	Rolled up to SI	<p>Summary: This paragraph establishes requirements (1) for rotor mass balance to prevent excessive vibration at speeds out to the maximum forward speed and (2) for substantiation of the structural integrity of the mass balance.</p> <p>Rationale: Rotor mass balance affects structural integrity, but the definitions of “excessive” and “maximum forward speed” for a UAS under the ConOps may differ from Part 27 rotorcraft. The paragraph was included in the more generalized requirements of the SI Issue Paper.</p>	
§27.661 Rotor blade clearance	Rolled up to SI	<p>Summary: This paragraph establishes a requirement that the rotor blades not contact any part of the structure during any operating condition.</p> <p>Rationale: While this requirement relates to maintaining rotor system integrity under most conditions, there might be exceptions related to autorotations away from the operational boundaries where the vehicle could sustain damage or loss without hazard to persons or property. The requirement was included in the rollup to allow discussion of tailoring the requirement to the specific design and operations of the UAS.</p>	
§27.663 Ground resonance prevention means	Rolled up to SI	<p>Summary: This paragraph establishes requirements on the means incorporated in the rotorcraft design to avoid ground resonance and a requirement that failure of any single means will not cause ground resonance.</p> <p>Rationale: Avoidance of ground resonance was considered an important aspect of maintaining rotor system integrity, particularly near (ground) crewmembers involved in the servicing the vehicle. The requirements for establishing the reliability of such systems, however, might be different for unmanned vehicles than for manned vehicles, so the paragraph was rolled up.</p>	
Control Systems			
§27.671 General	Rolled up to CMS (a and b)	<p>Summary: This paragraph establishes requirements on smoothness of the control systems and a requirement that they be designed or marked to minimize probability of incorrect assembly.</p> <p>Rationale: Requirements for smoothness of the control system are dictated by the design and power of the automatic control system and its servos, which must satisfy the flight requirements of CMS(a). The design and marking requirements to minimize incorrect assembly are covered in CMS(b).</p>	

§27.672 Stability augmentation, automatic, and power-operated systems	Rolled up to CMS(a)	<p>Summary: This paragraph requires that any automatic stabilization or automatic control systems must be able to continue to a safe landing after any single failure in the system. The paragraph further specifies that the controllability and maneuverability requirements previously specified continue to be met within a “practical operational envelope”. Other parts of the paragraph relate to warning systems and pilot skill and strength requirements.</p> <p>Rationale: Although pilot-related requirements are not applicable under this ConOps, the requirements for controllability and maneuverability were rolled up with the expectation that the applicant and regulatory authority will determine the applicable requirements for the automatic flight control system of the AgR-1.</p>
§27.673 Primary flight control	Excluded	<p>Summary: Defines what a primary flight control is relative to a pilot.</p> <p>Rationale: Out of ConOps scope. Pilot does not have inner-loop control.</p>
§27.674 Interconnected controls	Excluded	<p>Summary: Ensures that safe flight can continue after a jam or other malfunction of an auxiliary interconnected flight control.</p> <p>Rationale: Out of vehicle scope. AgR-1 does not use interconnected auxiliary controls.</p>
§27.675 Stops	Rolled up to CMS(b)	<p>Summary: This paragraph specifies that the control system must contain stops that limit the range of control motion and conditions that must be considered in setting the stops.</p> <p>Rationale: While a UAS will not have traditional pilot controls and thus the need for stops to limit pilot control inputs, there still exists a requirement to ensure that the control system actuators cannot produce commands that would cause a failure condition in the control system and thus jeopardize rotor system integrity. This requirement generally applies and was included in the CMS(b).</p>
§27.679 Control system locks	Rolled up to CMS(b)	<p>Summary: This paragraph establishes requirements for control system locks if they are part of the design.</p> <p>Rationale: Although the operational concept would not likely dictate a requirement for control system locks, the requirement for ground transportability could possibly dictate a requirement and was included in the rollup.</p>
§27.681 Limit load static tests	Rolled up to CMS(b) and SI	<p>Summary: This paragraph establishes the conditions under which compliance with control system limit loads must be shown.</p> <p>Rationale: Since the integrity of the control system is essential to maintaining the integrity of the rotor system, this paragraph may be generally applicable and was included in the rollup for CMS(b).</p>
§27.683 Operation tests	Rolled up to CMS(b)	<p>Summary: This paragraph specifies that the control system must be free of jamming, excessive friction, and excessive deflection when operated from the pilot compartment to the loads specified for the system.</p> <p>Rationale: While the UAS does not have an on board pilot compartment, the spirit of the rule is that the control system be free of the specified characteristics when operated by power actuators. What constitutes “excessive” might vary for an automatic control system compared with a manual control system and would probably be limited by required control system performance.</p>
§27.685 Control system details	Rolled up to CMS(b)	<p>Summary: This paragraph specifies a number of miscellaneous requirements for control system functioning to prevent jamming, chafing, and interference from cargo, passengers, loose objects or the freezing of moisture. This applies primarily to pulley and cable systems. Special design factors for push-pull and cable systems are also specified.</p> <p>Rationale: The general intent that the control system design should consider jamming, chafing and interference applies in general. Applicability of the specific details in the paragraph will depend on implementation of the control system.</p>

§27.687 Spring devices	Rolled up to CMS(b)	Summary: This paragraph requires that spring devices whose failure could compromise safe flight need to be reliable and must be shown as such by demonstrations simulating service conditions. Rationale: Failure of spring devices in the control system could result in flutter or other unsafe conditions and thus could represent a threat to control system and rotor system integrity. The paragraph was rolled up to ensure that the applicant considers the requirements on spring devices to the extent they are included in the design.
§27.691 Autorotation control mechanism	Modified	<i>If autorotation capability is implemented,</i> each main rotor blade pitch control mechanism must allow rapid entry into autorotation after power failure Rationale: The autorotation function may not be required by the ConOps (e.g., max altitude restrictions and acceptability of hull loss).
§27.695 Power boost and power-operated control system	Rolled up to CMS(b)	Summary: This paragraph specifies requirements for an alternate control system to provide continued safe flight in the event of a failure of a power actuator or any of the elements supporting the actuator, such as pumps, valves, and lines. The paragraph includes requirements on the reliability of mechanical parts and actuators. Rationale: The requirements of this paragraph are generally applicable given the use of servos in the primary flight control system of the AgR-1, although only to the extent that failure to meet the requirements would jeopardize rotor system integrity. The paragraph was rolled up in CMS(b) as a consideration in control system design and installation.
<b>Landing Gear</b>		
§27.723 Shock absorption tests	Excluded	Summary: This paragraph describes conditions for executing the required shock absorption tests. Rationale: Secondary hazard.
§27.725 Limit drop test	Excluded	Summary: This paragraph describes the impulsive load the landing gear is capable of withstanding without collapse. Rationale: Does not map to a hazard.
§27.727 Reserve energy absorption drop test	Excluded	Summary: This paragraph describes the amount of impact energy the landing gear must be capable of absorbing without collapse. Rationale: Does not map to a hazard.
§27.729 Retracting mechanism	Excluded	Summary: This paragraph describes the requirements for retractable landing gear. Rationale: Does not map to a hazard. This assumes there are no other hazards associated with retractable landing gear beyond ground resonance
§27.731 Wheels	Excluded	Summary: This paragraph describes wheel requirements for the landing gear. Rationale: Does not map to a hazard.
§27.733 Tires	Excluded	Summary: This paragraph describes the performance requirements of the tires in the landing gear. Rationale: Does not map to a hazard.
§27.735 Brakes	Rolled up to CMS(a)	Summary: This paragraph establishes functional requirements for the brakes including design requirements related to startup, shutdown, landing, and while parked on a 10 degree slope. Rationale: If equipped with a wheel system, this requirement mitigates the hazard of the vehicle unintentionally moving under the required conditions.
§27.737 Skis	Excluded	Summary: This paragraph describes limit loading for landing on skis. Rationale: Out of ConOps scope.

Floats and Hulls		
§27.751 Main float buoyancy	Excluded	Summary: This paragraph describes buoyancy requirements on the vehicle. Rationale: Out of ConOps scope.
§27.753 Main float design	Excluded	Summary: This paragraph describes design requirements on buoyancy elements. Rationale: Out of ConOps scope.
§27.755 Hulls	Excluded	Summary: This paragraph describes the buoyancy requirements on the vehicle in the case of hull damage. Rationale: Out of ConOps scope.
Personnel and Cargo Accommodations		
§27.771 Pilot compartment	Excluded	Summary: This paragraph deals with the accommodations necessary for an onboard pilot. Rationale: Does not map to a hazard.
§27.773 Pilot compartment view	Excluded	Summary: This paragraph deals with the accommodations necessary for an onboard pilot. Rationale: Does not map to a hazard.
§27.775 Windshields and windows	Excluded	Summary: This paragraph deals with the accommodations (windshields and windows) necessary for an onboard pilot to see outside of the aircraft. Rationale: Does not map to a hazard.
§27.777 Cockpit controls	Excluded	Summary: This paragraph deals with the accommodations (cockpit controls) necessary for an onboard pilot to control the aircraft. Rationale: Does not map to a hazard.
§27.779 Motion and effect of cockpit controls	Excluded	Summary: This paragraph deals with the accommodations necessary for motion relevant to cockpit controls for an onboard pilot. Rationale: Does not map to a hazard.
§27.783 Doors	Excluded	Summary: This paragraph deals with external doors necessary for onboard persons to safely exit the aircraft. Rationale: Does not map to a hazard.
§27.785 Seats, berths, litters, safety belts, and harnesses	Excluded	Summary: This paragraph deals with the seating accommodations (e.g., seatbelts, seats, or harnesses) necessary for onboard persons. Rationale: Does not map to a hazard.
§27.787 Cargo and baggage compartments	Excluded	Summary: This paragraph deals with the cargo and baggage compartments to stow articles for onboard persons. Rationale: Does not map to a hazard.
§27.801 Ditching	Excluded	Summary: This paragraph deals with the accommodations necessary for the safety onboard persons in the event of ditching. Rationale: Does not map to a hazard.

§27.805 Flight crew emergency exits	Excluded	Summary: This paragraph deals with the accommodations necessary for emergency exits (onboard) for the flight crew. Rationale: Does not map to a hazard.	
§27.807 Emergency exits	Excluded	Summary: This paragraph deals with the accommodations necessary for emergency exits for onboard passengers. Rationale: Does not map to a hazard.	
§27.831 Ventilation	Excluded	Summary: This paragraph deals with the accommodations necessary for the ventilation system to prevent fuel fumes and carbon monoxide from harming onboard persons. Rationale: Does not map to a hazard.	
§27.833 Heaters	Excluded	Summary: This paragraph requires approval of any combustion heaters necessary for the accommodation of onboard persons. Rationale: Does not map to a hazard.	
Fire Protection			
§27.853 Compartment interiors	Excluded	Summary: This paragraph deals with onboard fire protection for compartments used by crew or passengers. Rationale: Does not map to a hazard.	
§27.855 Cargo and baggage compartments	Excluded	Summary: This paragraph deals with onboard fire protection for cargo and baggage compartments. Rationale: Does not map to a hazard.	
§27.859 Heating systems	Excluded	Summary: This paragraph deals with onboard fire and carbon monoxide protection related to heating systems. Rationale: Does not map to a hazard.	
§27.861 Fire protection of structure, controls, and other parts	Modified	Each part of the structure, controls, rotor mechanism, and other parts essential to <i>preventing loss of containment or ejection of high energy parts</i> a controlled landing that would be affected by powerplant fires must be fireproof or protected so they can perform their essential functions for at least 5 minutes under any foreseeable powerplant fire conditions.	Rationale: Need fire protection sufficient to mitigate safety-critical hazards. The time requirement may need further consideration.
§27.863 Flammable fluid fire protection	Modified	<del>(a) In each area where flammable fluids or vapors might escape by leakage of a fluid system, there must be means to minimize the probability of ignition of the fluids and vapors, and the resultant hazards if ignition does occur.</del> <del>(b) Compliance with paragraph (a) of this section must be shown by analysis or tests, and the following factors must be considered:</del> <del>(1) Possible sources and paths of fluid leakage, and means of detecting leakage.</del> <del>(2) Flammability characteristics of fluids, including effects of any combustible or absorbing materials.</del> <del>(3) Possible ignition sources, including electrical faults, overheating of equipment,</del>	Rationale: The control of the flammable fluid hazard is not related to the act of fire protection for onboard crew and passengers of the rotorcraft, but instead centered around fire protection for the UAS crew and bystanders. Hence, subparagraph (b)(4) was kept because it pertains to having sufficient means for fire control (equipment, access to electrical cutoffs, operational procedures etc.) available to UAS crew.  The loss of hull integrity of the rotorcraft within the containment region is not a hazard, so the rotorcraft structure itself need not be protected from flammable fluid ignition.

		<del>and malfunctioning of protective devices.</del> <del>(4) Means available for controlling or extinguishing a fire, such as stopping flow of fluids, shutting down equipment, fireproof containment, or use of extinguishing agents <i>provided either by the type design or through operational requirements and provisions.</i></del> <del>(5) Ability of rotorcraft components that are critical to safety of flight to withstand fire and heat.</del> <del>(c) If action by the flight crew is required to prevent or counteract a fluid fire (e.g., equipment shutdown or actuation of a fire extinguisher) quick acting means must be provided to alert the crew.</del> <del>(d) Each area where flammable fluids or vapors might escape by leakage of a fluid system must be identified and defined.</del>	
External Loads			
§27.865 External loads.	Excluded	Summary: This paragraph deals with the requirements for attaching external loads to the vehicle. Rationale: Out of vehicle scope. Secondary hazard. The spray system is assumed to be an external load (but not a jettisonable one).	
Miscellaneous			
§27.871 Leveling marks	Excluded	Summary: This paragraph requires marking in order to level the rotorcraft to affect stability (for loading conditions) Rationale: Does not map to a hazard.	
§27.873 Ballast provisions	Excluded	Summary: This paragraph requires preventative measures so that ballast does not shift in flight Rationale: Does not map to a hazard.	
Subpart E—Powerplant			
General			
§27.901 Installation	Excluded	Summary: This paragraph defines powerplant installation and establishes high-level safety requirements for continued operations between inspections/overhauls, electrical connections, accessibility, etc., and requires installation in accordance with Part 33 requirements. Rationale: Out of vehicle scope. Secondary hazard. The high-level safety requirements were, in part, established to provide safety for onboard occupants, which would not apply to a UAS. Use of a Part 33 certified engine is not required, and thus Part 33 installation requirements would not apply. Minimum safety requirements relevant to the UAS powerplant are covered adequately in other paragraphs and the PPS rollup.	
§27.903 Engines	Modified	<del>(a) <i>Engine type certification.</i> Each engine must have an approved type certificate. Reciprocating engines for use in helicopters must be qualified in accordance with §33.49(d) of this chapter or be otherwise approved for the intended usage.</del> <del>(b) <i>Engine or drive system cooling fan blade protection.</i> (1) If an engine or rotor</del>	Rationale: Subparagraph (a) is deleted because a certified engine is not required, as hull loss inside the containment region is not catastrophic. Subparagraph (b) is deleted because the unmanned rotorcraft does not need to be protected if a fan blade fails, as hull loss in the containment area is not catastrophic.

	<p><del>drive system cooling fan is installed, there must be a means to protect the rotorcraft and allow a safe landing if a fan blade fails. This must be shown by showing that —</del></p> <p><del>(i) The fan blades are contained in case of failure;—</del></p> <p><del>(ii) Each fan is located so that a failure will not jeopardize safety; or—</del></p> <p><del>(iii) Each fan blade can withstand an ultimate load of 1.5 times the centrifugal force resulting from operation limited by the following:—</del></p> <p><del>(A) For fans driven directly by the engine —</del></p> <p><del>(1) The terminal engine r.p.m. under uncontrolled conditions; or—</del></p> <p><del>(2) An overspeed limiting device.—</del></p> <p><del>(B) For fans driven by the rotor drive system, the maximum rotor drive system rotational speed to be expected in service, including transients.—</del></p> <p><del>(2) Unless a fatigue evaluation under §27.571 is conducted, it must be shown that cooling fan blades are not operating at resonant conditions within the operating limits of the rotorcraft.—</del></p> <p><del>(e) Turbine engine installation. For turbine engine installations, the powerplant systems associated with engine control devices, systems, and instrumentation must be designed to give reasonable assurance that those engine operating limitations that adversely affect turbine rotor structural integrity will not be exceeded in service.</del></p> <p><del>(d) Restart capability: A means to restart any engine in flight must be provided.—</del></p> <p><del>(1) Except for the in flight shutdown of all engines, engine restart capability must be demonstrated throughout a flight envelope for the rotorcraft.—</del></p> <p><del>(2) Following the in flight shutdown of all engines, in flight engine restart capability must be provided.—</del></p>	<p>Subparagraph (c) is kept because it helps mitigate hazards associated with high energy parts exiting the containment area.</p> <p>Subparagraph (d) is deleted because restart capability is not required as hull loss in the containment area is not catastrophic.</p>
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§27.907 Engine vibration	Modified	<p><del>(a) Each engine must be installed to prevent the harmful vibration of any part of the engine or rotorcraft.</del></p> <p><del>(b) The addition of the rotor and the rotor drive system to the engine may not subject the principal rotating parts of the engine to excessive vibration stresses. This must be shown by a vibration investigation.</del></p> <p>(c) No part of the rotor drive system may be subjected to excessive vibration stresses.</p>	<p>Rationale: Subparagraphs (a) and (b) were deleted because engine integrity itself is not needed.</p> <p>Subparagraph (c) was kept because rotor drive integrity must be protected from destructive vibration, as this may lead to the hazard of high energy parts being ejected from the containment area.</p>
Rotor Drive System			
§27.917 Design	Modified	<p>(a) Each rotor drive system must incorporate a unit for each engine to automatically disengage that engine from the main and auxiliary rotors if that engine fails.</p> <p><del>(b) Each rotor drive system must be arranged so that each rotor necessary for control in autorotation will continue to be driven by the main rotors after disengagement of the engine from the main and auxiliary rotors.</del></p> <p><del>(c) If a torque limiting device is used in the rotor drive system, it must be located so as to allow continued control of the rotorcraft when the device is operating.</del></p> <p>(d) The rotor drive system includes any part necessary to transmit power from the engines to the rotor hubs. This includes gear boxes, shafting, universal joints, couplings, rotor brake assemblies, clutches, supporting bearings for shafting, any attendant accessory pads or drives, and any cooling fans that are a part of, attached to, or mounted on the rotor drive system.</p>	<p>Rationale: Subparagraphs (a) and (d) are kept because rotors must be protected from engine seizures/failures to prevent high energy parts from being ejected from the containment area.</p> <p>Subparagraphs (b) and (c) were deleted because neither autorotation nor a torque limiting device are required functions, and this hazard may be mitigated via operational means (e.g., limited altitude).</p>
§27.921 Rotor brake	As is	If there is a means to control the rotation of the rotor drive system independently of the engine, any limitations on the use of that means must be specified, and the control for that means must be guarded to prevent inadvertent operation.	Rationale: A rotor brake engaging inadvertently could lead to rotor integrity being compromised.
§27.923 Rotor drive system and control mechanism tests	Excluded	<p>Summary: This paragraph establishes specific hourly or cycle requirements for testing of rotor systems and associated components.</p> <p>Rationale: Multiengine requirements of this paragraph are Out of vehicle scope. Other testing requirements would not be directly applicable to the AgR-1 and ConOps given that hull loss is acceptable under some circumstances.</p>	

§27.927 Additional tests	Excluded	<p>Summary: This paragraph defines additional rotor system tests that apply if the torque going from the engine to the transmission is not under direct pilot control and other conditions specific to multi-engine turbine installations.</p> <p>Rationale: Out of vehicle scope. Mitigated by other regulation. This paragraph was excluded because multiple engines are out of scope and additional tests are unnecessarily burdensome for the operational context.</p>	
§27.931 Shafting critical speed	As is	<p>(a) The critical speeds of any shafting must be determined by demonstration except that analytical methods may be used if reliable methods of analysis are available for the particular design.</p> <p>(b) If any critical speed lies within, or close to, the operating ranges for idling, power on, and autorotative conditions, the stresses occurring at that speed must be within safe limits. This must be shown by tests.</p> <p>(c) If analytical methods are used and show that no critical speed lies within the permissible operating ranges, the margins between the calculated critical speeds and the limits of the allowable operating ranges must be adequate to allow for possible variations between the computed and actual values.</p>	Rationale: This requirement is important to maintain rotor drive shaft system integrity.
§27.935 Shafting joints	As is	Each universal joint, slip joint, and other shafting joints whose lubrication is necessary for operation must have provision for lubrication.	Rationale: This requirement is important to maintain rotor drive shaft system integrity.
§27.939 Turbine engine operating characteristics	Modified	<p><del>(a) Turbine engine operating characteristics must be investigated in flight to determine that no adverse characteristics (such as stall, surge, or flameout) are present, to a hazardous degree, during normal and emergency operation within the range of operating limitations of the rotorcraft and of the engine.</del></p> <p><del>(b) The turbine engine air inlet system may not, as a result of airflow distortion during normal operation, cause vibration harmful to the engine.</del></p> <p>(c) For governor-controlled engines, it must be shown that there exists no hazardous torsional instability of the drive system associated with critical combinations of power, rotational speed, and control displacement.</p>	Rationale: Subparagraphs (a) and (b) were excluded because they do not relate to a hazard. However, subparagraph (c) is relevant because the hazard of over-torque of the transmission/rotor system from loss of governor control should be mitigated to prevent loss of rotor system integrity.
Fuel System			
§27.951 General	Excluded	<p>Summary: This paragraph establishes requirements for fuel system design and installation to ensure continued operation of the engine.</p> <p>Rationale: Mitigated by other regulation.</p>	

§27.952 Fuel system crash resistance	Excluded	Summary: This paragraph establishes design and testing requirements for fuel tanks. Rationale: Secondary hazard. The fuel tank does not need to meet crashworthiness requirements for manned vehicles.	
§27.953 Fuel system independence	Excluded	Summary: This paragraph establishes requirements for single and multiple fuel tanks in multiengine rotorcraft. Rationale: Out of vehicle scope.	
§27.954 Fuel system lightning protection	Excluded	Summary: This paragraph establishes requirements for fuel system protection from lightning strikes. Rationale: Out of ConOps scope. The ConOps assumes no operations in thunderstorms. Risk associated with the possibility of a lightning strike on the ground and potential harm to the crew should be considered in operational procedures.	
§27.955 Fuel flow	Excluded	Summary: This paragraph establishes requirements to ensure stable fuel flow to the engine. Rationale: Mitigated by other regulation.	
§27.959 Unusable fuel supply	Excluded	Summary: This paragraph establishes requirements to determine minimum usable fuel. Rationale: Mitigated by other regulation.	
§27.961 Fuel system hot weather operation	Excluded	Summary: This paragraph establishes requirements for fuel system operations at fuel temperature up to 110 deg. F. Rationale: Mitigated by other regulation.	
§27.963 Fuel tanks: general	Rolled-up to PPS	Summary: This paragraph establishes general requirements for fuel tank design, construction and installation, including such features as baffling, vibration resistance, inertia and fuel loading structural requirements, and ventilation requirements. Rationale: These requirements are necessary in some form to mitigate a possible explosion hazard should fuel escape from the fuel tank during operations. The requirements were rolled up into a general statement that the applicant determines safety critical conditions including consideration of fuel tank design, construction, and installation.	
§27.965 Fuel tank tests	Rolled-up to PPS	Summary: This paragraph specifies conditions under which fuel tanks must be tested to show structural integrity, including pressures, times, vibrations, etc. Rationale: As in §27.963, this paragraph relates to ensuring explosion resistance of the fuel tank installation and was rolled up into the generalized requirements for the powerplant and supporting systems.	
§27.967 Fuel tank installation	Rolled up to PPS	Summary: This paragraph requires that fuel tanks be installed in such a way that they are properly supported and provided adequate protection against expected loads. Rationale: This paragraph was rolled up for the same reasons as §27.963 and §27.965.	
§27.969 Fuel tank expansion space	As is	Each fuel tank or each group of fuel tanks with interconnected vent systems must have an expansion space of not less than 2 percent of the tank capacity. It must be impossible to fill the fuel tank expansion space inadvertently with the rotorcraft in the normal ground attitude.	Rationale: Fuel tank should not be overfilled, because this might lead to possible inadvertent ignition.
§27.971 Fuel tank sump	Excluded	Summary: This paragraph establishes requirements for a drainable fuel sump and sets minimum size to minimize possibility of water or sediment in the fuel which could lead to engine malfunction. Rationale: Mitigated by other regulation.	

§27.973 Fuel tank filler connection	Modified	<p>(a) Each fuel tank filler connection must prevent the entrance of fuel into any part of the rotorcraft other than the tank itself during normal operations <del>and must be crash-resistant during a survivable impact in accordance with §27.952(e).</del> In addition—</p> <p>(1) Each filler must be marked as prescribed in §27.1557(c)(1);</p> <p>(2) Each recessed filler connection that can retain any appreciable quantity of fuel must have a drain that discharges clear of the entire rotorcraft; and</p> <p>(3) Each filler cap must provide a fuel-tight seal under the fluid pressure expected in normal operation <del>and in a survivable impact.</del></p> <p>(b) Each filler cap or filler cap cover must warn when the cap is not fully locked or seated on the filler connection.</p>	<p>Rationale: Fuel must stay in the fuel tank to avoid possible inadvertent ignition. This protects the ground crew (e.g., when the rotorcraft is landing or taking off). Fuel tank filler connections need not preserve hull integrity during a crash because the fuel system itself is not required to be crash resistant.</p> <p>Subparagraph (3) was kept because fuel vapors leaking from a loose or faulty fuel cap could be an inflight or ground fire or explosion hazard. Thus the filler cap should be required to provide a fuel-tight seal.</p> <p>Subparagraph (b) was kept because ground crew must be warned if the filler cap is not properly locked or seated on the filler connection, in order to preserve ground crew safety.</p>
§27.975 Fuel tank vents	Modified	<p>(a) Each fuel tank must be vented from the top part of the expansion space so that venting is effective under all normal flight conditions. Each vent must minimize the probability of stoppage by dirt or ice.</p> <p>(b) The venting system must be designed to minimize spillage of fuel through the vents to an ignition source in the event of a rollover during landing <i>or</i> ground operation; <del>or a survivable impact.</del></p>	<p>Rationale: Venting is required to preserve ground crew safety. Design for survivable impact is not necessary because there are no humans on board.</p>
§27.977 Fuel tank outlet	Excluded	<p>Summary: This paragraph establishes requirements for fuel outlets and strainers that relate to maintaining fuel flow to the engine.</p> <p>Rationale: Secondary hazard.</p>	
Fuel System Components			
§27.991 Fuel pumps	Excluded	<p>Summary: This paragraph establishes failure conditions that must not jeopardize compliance with §27.955.</p> <p>Rationale: Mitigated by other regulation. The requirements of §27.955 were also excluded.</p>	
§27.993 Fuel system lines and fittings	Rolled up to PPS	<p>Summary: This paragraph sets requirements for fuel lines and fittings that safely accommodate high temperatures, vibration, and relative motion of components.</p> <p>Rationale: Failure to comply with the spirit of these requirements in some form could result in a fuel system explosion hazard, but the requirement as written might be too restrictive for an unmanned system design that could tolerate hull losses under some conditions. Thus, the requirement was rolled up as part of the more general requirements for the powerplant and supporting systems.</p>	

§27.995 Fuel valves	Rolled up to PPS	Summary: This paragraph establishes requirements for the locations, responsiveness, and controls for fuel valves. Rationale: As in §27.993, failure to comply with the spirit of these requirements in some form could result in a fuel system explosion hazard, but the requirement as written might be too restrictive for an unmanned system design that could tolerate hull losses under some conditions. The requirement was rolled up under the more general requirements of the powerplant and supporting systems.
§27.997 Fuel strainer or filter	Excluded except for (c), which is rolled up to PPS	Summary: This paragraph establishes requirements for fuel strainers and filters. Subparagraph (c) establishes requirements for structural mounting of any fuel strainer or filter installed. Rationale: Failure of the fuel filter/strainer mounting (if installed) could lead to a failure to contain fuel within the fuel system and an explosion hazard. Subparagraph (c) was rolled up into PPS.
§27.999 Fuel system drains.	Excluded except for (b)(2), which is rolled up to PPS	Summary: This paragraph establishes requirements on fuel system drains. Subparagraph (b)(2) establishes requirements for positive closure of fuel system drains. Rationale: Since leaking fuel from a fuel system drain could represent an explosion hazard, this subparagraph was rolled up to PPS for consideration during powerplant and supporting systems design.
<b>Oil System</b>		
§27.1011 Engines: General	Excluded	Summary: This paragraph establishes design requirements for engine oil system(s) that ensure adequate oil supply to the engine under continuous operations. Rationale: Mitigated by other regulation.
§27.1013 Oil tanks	Rolled up to PPS	Summary: This paragraph establishes general requirements for oil tank design, construction and installation. Rationale: These requirements may be necessary in some form to mitigate a possible explosion hazard should oil escape from the oil tank during operations. The requirements were rolled up into the general requirements of the PPS Issue Paper.
§27.1015 Oil tank tests	Rolled up to PPS	Summary: This paragraph specifies conditions under which oil tanks must be tested to show structural integrity. Rationale: As in §27.965 for fuel tank testing, this paragraph was considered to relate to ensuring explosion resistance of the oil tank installation and was rolled up into the generalized requirements for the powerplant and supporting systems.
§27.1017 Oil lines and fittings	Rolled up to PPS	Summary: This paragraph sets requirements for oil lines and fittings that safely accommodate high temperatures, vibration and relative motion of components. Rationale: Similar to the reasoning for §27.997 for fuel system lines and fittings, failure to comply with the spirit of these requirements in some form could result in an oil system explosion hazard. Thus, this requirement was rolled up as part of the more general requirements for the powerplant and supporting systems.
§27.1019 Oil strainer or filter	Excluded	Summary: This paragraph establishes requirements for oil strainers, filters, and bypasses that ensure uninterrupted flow of oil to the engine. Rationale: Mitigated by other regulation.
§27.1021 Oil system drains	Rolled up to PPS	Summary: Similar to the requirements of §27.999 for fuel system drains, this requirement establishes requirements for positive closure of oil system drains. Rationale: Since leaking oil from an oil system drain could represent an explosion hazard, this subparagraph was rolled up to PPS for consideration during powerplant and supporting systems design.

<p>§27.1027 Transmission and gearboxes</p>	<p>Modified</p>	<p><del>(a) The lubrication system for components of the rotor drive system that require continuous lubrication must be sufficiently independent of the lubrication systems of the engine(s) to ensure lubrication during autorotation.</del></p> <p><del>(b) Pressure lubrication systems for transmissions and gearboxes must comply with the engine oil system requirements of §§27.1013 (except paragraph (e)), 27.1015, 27.1017, 27.1021, and 27.1337(d).</del></p> <p><del>(c) Each pressure lubrication system must have an oil strainer or filter through which all of the lubricant flows and must —</del></p> <p><del>(1) Be designed to remove from the lubricant any contaminant which may damage transmission and drive system components or impede the flow of lubricant to a hazardous degree;</del></p> <p><del>(2) Be equipped with a means to indicate collection of contaminants on the filter or strainer at or before opening of the bypass required by paragraph (c)(3) of this section; and</del></p> <p><del>(3) Be equipped with a bypass constructed and installed so that —</del></p> <p><del>(i) The lubricant will flow at the normal rate through the rest of the system with the strainer or filter completely blocked; and</del></p> <p><del>(ii) The release of collected contaminants is minimized by appropriate location of the bypass to ensure that collected contaminants are not in the bypass flowpath.</del></p> <p><del>(d) For each lubricant tank or sump outlet supplying lubrication to rotor drive systems and rotor drive system components, a screen must be provided to prevent entrance into the lubrication system of any object that might obstruct the flow of lubricant from the outlet to the filter required by paragraph (c) of this section. The requirements of paragraph (c) do not apply to screens installed at lubricant tank or sump outlets.</del></p> <p><del>(e) Splash type lubrication systems for rotor drive system gearboxes must comply with §§27.1021 and 27.1337(d).</del></p>	<p>Rationale: Subparagraph (a) was kept because lubrication of the rotor drive system must continue independently of engine lubrication system in order to maintain rotor drive system integrity and prevent high energy parts from exiting the containment area.</p> <p>Other than this, lubrication of the transmission and gearboxes need not be required to maintain hull integrity.</p>
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Cooling		
§27.1041 General	Rolled up to PPS	<p>Summary: This paragraph establishes requirements that the cooling system be capable of maintaining the temperatures of powerplant components, including rotor system components, within established temperature limits under critical surface and flight operating conditions.</p> <p>Rationale: Since compliance with the general requirements of this paragraph could affect rotor system integrity the requirement was rolled up for consideration in the generalized requirements of the PPS Issue Paper.</p>
§27.1043 Cooling tests	Excluded	<p>Summary: Along with §27.1045, this paragraph establishes conditions and requirements for conducting cooling tests on engines.</p> <p>Rationale: Specific tests for cooling are excluded in deference to the general proof of compliance requirements in §27.21.</p>
§27.1045 Cooling test procedures	Excluded	<p>Summary: Along with §27.1043, this paragraph establishes conditions and requirements for conducting cooling tests on engines.</p> <p>Rationale: Specific test procedures for cooling are excluded in deference to the general proof of compliance requirements in §27.21.</p>
Induction System		
§27.1091 Air induction	Rolled up to PPS	<p>Summary: This paragraph establishes requirements for air induction systems. In particular, if fuel can accumulate in the system, the system must have drains that discharge fuel clear of the rotorcraft and out of the path of exhaust flames. Additionally, for turbine powered rotorcraft, the paragraph requires that there must be means to prevent hazardous quantities of fuel leakage or overflow from drains.</p> <p>Rationale: Since compliance with some of the provisions of this paragraph could relate to the mitigation of an explosion hazard, the requirement was rolled up into the generalized requirements of the PPS Issue Paper.</p>
§27.1093 Induction system icing protection	Excluded	<p>Summary: This paragraph establishes induction icing requirements for reciprocating and turbine engines and test conditions for demonstrating compliance. Preventing induction icing helps prevent damage to the engine and loss of performance.</p> <p>Rationale: Secondary hazard. For this application, damage to engine and loss of performance may be acceptable under some conditions.</p>
Exhaust System		
§27.1121 General	Rolled up to PPS	<p>Summary: This paragraph establishes requirements for the design and installation of the rotorcraft exhaust system to prevent ignition of flammable fluids or vapors and accommodate vibration, expansion, and other physical characteristics of the rotorcraft environment.</p> <p>Rationale: The requirements are applicable, but only to mitigate hazards to crewmembers during servicing and loading operations. The requirement was rolled up into the general requirements to PPS.</p>
§27.1123 Exhaust piping	Rolled up to PPS	<p>Summary: This paragraph establishes requirements for exhaust system design, including requirements that the exhaust system must prevent local hot spots and exhaust gases must discharge clear of fuel system components and drains. The paragraph also requires that exhaust system parts with a surface hot enough to ignite flammable fluids or vapors must be located or shielded so that leakage from any system carrying flammable fluids or vapors will not result in a fire.</p> <p>Rationale: Since this paragraph relates to design features that could prevent explosions, it was rolled up under the generalized requirements of the PPS Issue Paper.</p>

Powerplant Controls and Accessories		
§27.1141 Powerplant controls: general	Excluded except for (d) and (e), which are rolled up to PPS	Summary: This paragraph establishes requirements for design and operation of powerplant controls to ensure continued safe operations. Rationale: Subparagraph (d) is rolled up because verification of fuel valve position can be relevant to the pilot's safety roll. Subparagraph (e) is rolled up to ensure that loss of governor control for a turbine engine cannot jeopardize transmission or rotor system integrity due to over-torque.
§27.1143 Engine controls	Excluded	Summary: This paragraph establishes design requirements for fuel shutoffs and controls for multiple engines. Rationale: Out of vehicle scope.
§27.1145 Ignition switches	Excluded	Summary: This paragraph establishes design requirements to prevent inadvertent activation of ignition switches and gang operation of multiple ignition switches. Rationale: Out of vehicle scope.
§27.1147 Mixture controls	Excluded	Summary: This paragraph establishes requirements to be able to control mixtures for multiple engines both separately and together. Rationale: Out of vehicle scope.
§27.1151 Rotor brake controls	Rolled (a) up to CMS(a) and SI	Summary: Subparagraph (a) requires that it must be impossible to apply the rotor brake inadvertently in flight and that crew notification occur if a rotor brake is not released before takeoff Rationale: Inadvertent application of the rotor brake in flight while torque is being applied to the rotor would be a significant hazard to rotor system integrity. Thus, subparagraph (a) is a requirement on the design of the control system and is rolled up. Subparagraph (b) is excluded because a warning system is not required in the ground control station.
§27.1163 Powerplant accessories	Rolled up to PPS	Summary: This paragraph establishes requirements for mounting accessories to prevent damage to the engine or dragging on rotor system. Rationale: Requirements related to engine protection are not applicable. Subparagraph (b) establishes accessory drive requirements that relate to protecting the transmission and rotor system from excessive accessory drive loads. This requirement is rolled up.
Powerplant Fire Protection		
§27.1183 Lines, fittings, and components	Rolled up to PPS	Summary: This paragraph establishes requirements for fire resistance and fire proofing for fuel lines, fittings, and components. These requirements relate directly to preventing onboard fires and/or explosions. Rationale: The requirements as written may be too specific for an unmanned vehicle where hull losses can be tolerated under some conditions, so the requirements were rolled up into the more general language of the issue paper.
§27.1185 Flammable fluids	Rolled up to PPS	Summary: This paragraph establishes design and installation requirements for firewalls, fuel tanks, and fuel system components in areas where flammable fluids are present. Rationale: The requirements as written may be too specific for an unmanned vehicle where hull losses can be tolerated under some conditions, so the requirements were rolled up into the more general language of the issue paper.
§27.1187 Ventilation and drainage	Rolled up to PPS	Summary: This paragraph establishes requirements for ventilation and drainage for any compartment that contains part of the powerplant installation so as not to create a fire hazard. Rationale: The details of the paragraph were considered to be too specific for an unmanned aircraft, but there still exists a requirement to protect crew when servicing the helicopter. Lack of compliance with the spirit of the paragraph could create an explosion hazard, so the specific requirements of this paragraph were rolled up into the more general language of the issue paper.



§27.1189 Shutoff means	Rolled up to PPS	<p>Summary: This paragraph establishes requirements for a means to shut off each line carrying flammable fluids into the engine compartment, with a number of exceptions listed.</p> <p>Rationale: The details of the paragraph were considered too specific for an unmanned aircraft, but a lack of compliance with the spirit of this paragraph could present a hazard to crew when servicing the helicopter. The specific requirements of this paragraph were rolled up into the more general language of the issue paper.</p>	
§27.1191 Firewalls	Rolled up to PPS	<p>Summary: This paragraph establishes requirements for firewalls, or equivalents, to protect personnel compartments, structures, controls, rotor mechanisms, etc.</p> <p>Rationale: While there are no personnel compartments in the UAS to protect, the destruction of systems that could lead to a loss of rotor system integrity were considered relevant. The details of the paragraph were considered too specific for an unmanned aircraft, so the specific requirements of this paragraph were rolled up into the more general language of the issue paper.</p>	
§27.1193 Cowling and engine compartment covering	Rolled up to PPS and SI	<p>Summary: This paragraph establishes requirements for engine compartment covers that minimize fire hazards and protect rotor system components in the event of structural or mechanical failure of the normal retention means.</p> <p>Rationale: The requirements of the paragraph were considered relevant to protecting the integrity of the rotor system and relevant to protecting UAS crew during servicing. The paragraph was rolled up into the requirements of the issue paper.</p>	
§27.1194 Other surfaces	Excluded	<p>Summary: This paragraph requires fire resistance on surfaces aft of the engine compartment.</p> <p>Rationale: Does not map to a hazard.</p>	
§27.1195 Fire detector systems	Excluded	<p>Summary: This paragraph requires fire detectors in engine compartments that cannot be readily seen by the pilot.</p> <p>Rationale: Does not map to a hazard. Fire detection and warning systems are not required because engine fire is not a primary hazard.</p>	
Subpart F—Equipment			
General			
§27.1301 Function and Installation	Modified	<p>Each item of installed equipment, <i>whose failure could adversely affect safety</i>, must—</p> <p>(a) Be of a kind and design appropriate to its intended function;</p> <p>(b) Be labeled as to its identification, function, or operating limitations, or any applicable combination of these factors;</p> <p>(c) Be installed according to limitations specified for that equipment; and</p> <p>(d) Function properly when installed</p>	<p>Rationale: Since loss of vehicle may not have safety implications, this requirement is limited to only those pieces of equipment whose failure would affect safety.</p>
§27.1303 Flight and navigation instruments	Modified	<p><i>The applicant must demonstrate that sufficient information is provided to the pilot to monitor and control the flight path of the rotorcraft within the approved operational envelope.</i></p> <p><del>The following are the required flight and navigation instruments:</del></p> <p><del>(a) An airspeed indicator.</del></p> <p><del>(b) An altimeter.</del></p> <p><del>(c) A magnetic direction indicator.</del></p>	<p>Rationale: The original requirements presuppose that a pilot will have the ability to “hand-fly” the rotorcraft. This mode is not available with the operating limits of the AgR-1. The requirement is rewritten to ensure that sufficient information is provided to the pilot to monitor and control the flight path. We expect that the dominant role of the pilot is to monitor and not control the flight path.</p>

<p>§27.1305 Powerplant limitations</p>	<p>Modified</p>	<p>The following are the required powerplant instruments:</p> <p><del>(a) A carburetor air temperature indicator, for each engine having a preheater that can provide a heat rise in excess of 60 °F.</del></p> <p><del>(b) A cylinder head temperature indicator, for each—</del></p> <p><del>(1) Air cooled engine;</del></p> <p><del>(2) Rotorcraft with cooling shutters; and</del></p> <p><del>(3) Rotorcraft for which compliance with §27.1043 is shown in any condition other than the most critical flight condition with respect to cooling.</del></p> <p><del>(c) A fuel pressure indicator, for each pump fed engine.</del></p> <p><del>(d) A fuel quantity indicator, for each fuel tank.</del></p> <p><del>(e) A manifold pressure indicator, for each altitude engine.</del></p> <p>(f) An oil temperature warning device to indicate when the temperature exceeds a safe value in each main rotor drive gearbox (including any gearboxes essential to rotor phasing) having an oil system independent of the engine oil system.</p> <p>(g) An oil pressure warning device to indicate when the pressure falls below a safe value in each pressure-lubricated main rotor drive gearbox (including any gearboxes essential to rotor phasing) having an oil system independent of the engine oil system.</p> <p><del>(h)</del> An oil pressure indicator for each engine.</p> <p><del>(i)</del> An oil quantity indicator for each oil tank.</p> <p><del>(j)</del> An oil temperature indicator for each engine.</p> <p>(k) At least one tachometer to indicate the r.p.m. of each engine and, as applicable—</p> <p>(1) The r.p.m. of the single main rotor;</p> <p>(2) The common r.p.m. of any main rotors whose speeds cannot vary appreciably with respect to each other; or</p> <p>(3) The r.p.m. of each main rotor whose speed can vary appreciably with respect to that of another main rotor.</p> <p><del>(l) A low fuel warning device for each fuel tank which feeds an engine. This device must—</del></p> <p><del>(1) Provide a warning to the flightcrew when approximately 10 minutes of usable fuel remains in the tank; and</del></p>	<p>Rationale: Subparagraphs (a-e) were removed because they are not relevant to the turbine engine on the AgR-1. Subparagraphs (f-k,n,r,v) were retained since these conditions can result in structural failure of the engine, which relates to the rotor system integrity hazard. Subparagraphs (l-q,s) were removed because these requirements were provided to avoid in-flight engine shutdowns. The designated operation does not consider an in-flight engine shutdown a hazard.</p>
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		<p><del>(2) Be independent of the normal fuel quantity indicating system.</del></p> <p><del>(m) Means to indicate to the flight crew the failure of any fuel pump installed to show compliance with §27.955.</del></p> <p><del>(g) A gas temperature indicator for each turbine engine.</del></p> <p><del>(e) Means to enable the pilot to determine the torque of each turboshaft engine, if a torque limitation is established for that engine under §27.1521(e).</del></p> <p><del>(p) For each turbine engine, an indicator to indicate the functioning of the powerplant ice protection system.</del></p> <p><del>(q) An indicator for the fuel filter required by §27.997 to indicate the occurrence of contamination of the filter at the degree established by the applicant in compliance with §27.955.</del></p> <p><del>(h) For each turbine engine, a warning means for the oil strainer or filter required by §27.1019, if it has no bypass, to warn the pilot of the occurrence of contamination of the strainer or filter before it reaches the capacity established in accordance with §27.1019(a)(2).</del></p> <p><del>(s) An indicator to indicate the functioning of any selectable or controllable heater used to prevent ice clogging of fuel system components.</del></p> <p><del>(t) For rotorcraft for which a 30-second/2-minute OEI power rating is requested, a means must be provided to alert the pilot when the engine is at the 30-second and the 2-minute OEI power levels, when the event begins, and when the time interval expires.</del></p> <p><del>(u) For each turbine engine utilizing 30-second/2-minute OEI power, a device or system must be provided for use by ground personnel which—</del></p> <p><del>(1) Automatically records each usage and duration of power at the 30-second and 2-minute OEI levels;</del></p> <p><del>(2) Permits retrieval of the recorded data;</del></p> <p><del>(3) Can be reset only by ground maintenance personnel; and</del></p> <p><del>(4) Has a means to verify proper operation of the system or device.</del></p> <p><del>(i) Warning or caution devices to signal to the flight crew when ferromagnetic particles are detected by the chip detector required by §27.1337(e).</del></p>	
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§27.1307 Miscellaneous equipment	Modified	<p>The following is <del>the</del> required miscellaneous equipment <del>if its whose failure could adversely affect safety:</del></p> <p><del>(a) An approved seat for each occupant.</del></p> <p><del>(b) An approved safety belt for each occupant.</del></p> <p><del>(ae)</del> A master switch arrangement.</p> <p><del>(bd)</del> An adequate source of electrical energy, where electrical energy is necessary for operation of the rotorcraft.</p> <p><del>(ce)</del> Electrical protective devices <i>for those items with safety effects.</i></p>	<p>Rationale: This miscellaneous equipment is only required if its failure would affect safety. Since there are no vehicle occupants, there is no need for seats or seat belts. Ground control station operators are not located in moving vehicles. Electrical protective devices (e.g., fuses) are required to protect safety-critical systems. Electrical protection devices might benefit other electrical devices (e.g., spray equipment) but are not required for the rotorcraft to be airworthy.</p>
§27.1309 Equipment, systems, and installations	Modified	<p><del>(a)</del> The equipment, systems, and installations whose functioning is required <i>by this G-1U Issue Paper</i> <del>by this subchapter</del> must be designed and installed to ensure that they perform their intended functions under any foreseeable operating condition.</p> <p><del>(b) The equipment, systems, and installations of a multiengine rotorcraft must be designed to prevent hazards to the rotorcraft in the event of a probable malfunction or failure.</del></p> <p><del>(c)</del> The equipment, systems, and installations of single-engine rotorcraft must be designed to minimize hazards <del>to the rotorcraft</del> in the event of a probable malfunction or failure.</p>	<p>Rationale: Subparagraphs (a) and (c) apply. Subparagraph (b) was deleted because multiengine rotorcraft are beyond the scope of this issue paper.</p>
§27.1316 Electrical and electronic system lightning protection	Excluded	<p>Summary: This paragraph requires electronic components to continue to function correctly in the presence of lightning.</p> <p>Rationale: Out of ConOps scope.</p>	
§27.1317 High-intensity Radiated Fields Protection	Modified	<p><del>(a) Except as provided in paragraph (d) of this section, Each electrical and electronic system that performs a function whose failure <i>could adversely affect safety</i> would prevent the continued safe flight and landing of the rotorcraft must be designed and installed so that <i>they comply with HIRF considerations (TBD) determined to affect UAS.</i></del></p> <p><del>(1) The function is not adversely affected during and after the time the rotorcraft is exposed to HIRF environment I, as described in appendix D to this part;</del></p> <p><del>(2) The system automatically recovers normal operation of that function, in a timely manner, after the rotorcraft is exposed to HIRF environment I, as described in appendix D to this part, unless</del></p>	<p>Rationale: The text in subparagraph (a) was generalized to make clear that any HIRF-induced effects that could cause safety issues must be mitigated; however, the expected level of HIRF environmental conditions is not known at this time. Subparagraphs (a)(1-4), (b), (c), and (d) were excluded for this reason.</p>

		<p>this conflicts with other operational or functional requirements of that system;</p> <p>(3) The system is not adversely affected during and after the time the rotorcraft is exposed to HIRF environment II, as described in appendix D to this part; and</p> <p>(4) Each function required during operation under visual flight rules is not adversely affected during and after the time the rotorcraft is exposed to HIRF environment III, as described in appendix D to this part.</p> <p>(b) Each electrical and electronic system that performs a function whose failure would significantly reduce the capability of the rotorcraft or the ability of the flightcrew to respond to an adverse operating condition must be designed and installed so the system is not adversely affected when the equipment providing these functions is exposed to equipment HIRF test level 1 or 2, as described in appendix D to this part.</p> <p>(c) Each electrical and electronic system that performs a function whose failure would reduce the capability of the rotorcraft or the ability of the flightcrew to respond to an adverse operating condition, must be designed and installed so the system is not adversely affected when the equipment providing these functions is exposed to equipment HIRF test level 3, as described in appendix D to this part.</p> <p>(d) Before December 1, 2012, an electrical or electronic system that performs a function whose failure would prevent the continued safe flight and landing of a rotorcraft may be designed and installed without meeting the provisions of paragraph (a) provided —</p> <p>(1) The system has previously been shown to comply with special conditions for HIRF, prescribed under §21.16, issued before December 1, 2007;</p> <p>(2) The HIRF immunity characteristics of the system have not changed since compliance with the special conditions was demonstrated; and</p> <p>(3) The data used to demonstrate compliance with the special conditions is provided.</p>	
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Instruments: Installation			
§27.1321 Arrangement and visibility	Modified	<p>(a) Each flight, navigation, and powerplant instrument <del>for use by any pilot</del> <i>required for the pilot by this G-1U Issue Paper</i> must be easily visible to him.</p> <p><del>(b) For each multiengine rotorcraft, identical powerplant instruments must be located so as to prevent confusion as to which engine each instrument relates.</del></p> <p><del>(c) Instrument panel vibration may not damage, or impair the readability or accuracy of, any instrument.</del></p> <p><del>(d)</del> If a visual indicator is provided to indicate malfunction of an instrument <i>or system</i>, <del>it</del> <i>that indicator</i> must be effective under all probable <del>cockpit lighting</del> <i>operating</i> conditions.</p>	<p>Rationale: Subparagraph (a) was kept because instruments required by the UAS pilot should be easily visible.</p> <p>Subparagraph (b) was deleted because requirements for multiengine aircraft are beyond the scope of this issue paper.</p> <p>Subparagraph (c) was deleted because the instrument panel is not located inside the vehicle; any vibration of the instrument panel is incidental. Thus, no specific requirement is provided.</p> <p>Subparagraph (d) was kept. The pilot displays are located in a ground control station. The design and operation at this station must accommodate different lighting and operating conditions.</p>
§27.1322 Warning, caution, and advisory lights	Modified	<p>If warning, caution or advisory lights <del>are installed in the cockpit</del>, <i>required by the type design are installed in the ground control station</i>, they must, unless otherwise approved by the Administrator, be—</p> <p>(a) Red, for warning lights (lights indicating a hazard which may require immediate corrective action);</p> <p>(b) Amber, for caution lights (lights indicating the possible need for future corrective action);</p> <p>(c) Green, for safe operation lights; and</p> <p>(d) Any other color, including white, for lights not described in paragraphs (a) through (c) of this section, provided the color differs sufficiently from the colors prescribed in paragraphs (a) through (c) of this section to avoid possible confusion.</p>	<p>Rationale: Text was modified because the warning, caution, and advisory lights, if any, will be located in the ground control station instead of a cockpit.</p>
§27.1323 Airspeed indicating system	Excluded	<p>Summary: This paragraph provides various requirements for calibration of airspeed instruments.</p> <p>Rationale: Out of ConOps scope. The UAS pilot does not have inner loop control of vehicle, so an airspeed indicator is not required. A vendor could provide an airspeed indicator, but it is not required for continued safe flight and landing.</p>	
§27.1325 Static pressure systems	Modified	<p><del>(a) If a static system is installed</del>, each instrument with <i>a static air sensor</i> <del>case-connections</del> must be vented so that the influence of rotorcraft speed, <del>the opening and closing of windows</del>, airflow variation, and moisture or other foreign matter does not seriously affect its accuracy.</p> <p><del>(b) Each static pressure port must be designed and located in such manner that the correlation between air pressure in the static pressure system and true ambient atmospheric static pressure is not altered</del></p>	<p>Rationale: Some UAS may be designed without the need for a system to determine static pressure. Protection of static air sensors is related to maintaining controllability and stability, which is related to maintaining rotor system integrity (see CMS Issue Paper). Subparagraph (b) was removed because this requirement only applies in icing conditions that are outside the defined operational limits.</p> <p>Subparagraphs (c) and (d) were removed because the vehicle under consideration</p>

		<p><del>when the rotorcraft encounters icing conditions. An anti-icing means or an alternate source of static pressure may be used in showing compliance with this requirement. If the reading of the altimeter, when on the alternate static pressure system, differs from the reading of the altimeter when on the primary static system by more than 50 feet, a correction card must be provided for the alternate static system.</del></p> <p><del>(c) Except as provided in paragraph (d) of this section, if the static pressure system incorporates both a primary and an alternate static pressure source, the means for selecting one or the other source must be designed so that—</del></p> <p><del>(1) When either source is selected, the other is blocked off; and</del></p> <p><del>(2) Both sources cannot be blocked off simultaneously.</del></p> <p><del>(d) For unpressurized rotorcraft, paragraph (c)(1) of this section does not apply if it can be demonstrated that the static pressure system calibration, when either static pressure source is selected is not changed by the other static pressure source being open or blocked.</del></p>	<p>does not have multiple static pressure sources.</p>
§27.1327 Magnetic direction indicator	Excluded	<p>Summary: This paragraph provides various requirements for a magnetic director indicator (compass).</p> <p>Rationale: Out of ConOps scope. The UAS pilot does not have inner loop control of vehicle, so a magnetic direction indicator is not required. A vendor could provide a magnetic direction indicator, but it is not required for continued safe flight and landing.</p>	
§27.1329 Automatic pilot system	Modified	<p><del>(a) Each automatic pilot system must be designed so that the automatic pilot can—</del></p> <p><del>(1) Be sufficiently overpowered by one pilot to allow control of the rotorcraft; and</del></p> <p><del>(2) Be readily and positively disengaged by each pilot to prevent it from interfering with control of the rotorcraft.</del></p> <p><del>(b) Unless there is automatic synchronization, each system must have a means to readily indicate to the pilot the alignment of the actuating device in relation to the control system it operates.</del></p> <p><del>(c) Each manually operated control for the system's operation must be readily accessible to the pilots.</del></p> <p><del>(d) The system must be designed and adjusted so that, within the range of adjustment available to the pilot, it cannot produce hazardous loads on the rotorcraft or create hazardous deviations in the flight</del></p>	<p>Rationale: The requirements in §27.1329 presuppose a pilot is interacting with the autopilot to control the rotorcraft. The designated operation does not allow direct pilot control of rotorcraft servomechanisms; therefore, there is no need for requirements related to manual control of rotorcraft.</p> <p>The phrase “hazardous deviations of flight path” is interpreted to mean hazards to the vehicle itself (e.g., hazard of the vehicle ejecting high-energy parts) and it does not include hazards of the flight path itself (e.g., a vehicle exiting the containment region). Thus, the inclusion of this requirement does not mandate any particular architecture of the containment system or other parts of the UAS.</p>

		<p>path under any flight condition appropriate to its use, <del>either during normal operation or in the event of a malfunction, assuming that corrective action begins within a reasonable period of time.</del></p> <p><del>(e) If the automatic pilot integrates signals from auxiliary controls or furnishes signals for operation of other equipment, there must be positive interlocks and sequencing of engagement to prevent improper operation.</del></p> <p><del>(f) If the automatic pilot system can be coupled to airborne navigation equipment, means must be provided to indicate to the pilots the current mode of operation. Selector switch position is not acceptable as a means of indication.</del></p>	
§27.1335 Flight director systems	Excluded	<p>Summary: This paragraph provides a requirement to indicate the mode of the flight director to the crew.</p> <p>Rationale: Out of ConOps scope. The UAS pilot does not have inner loop control of vehicle, so a flight director is not needed. A vendor could provide a flight director, but it is not required for continued safe flight and landing.</p>	
§27.1337 Powerplant instruments	Rolled up to PPS	<p>Summary: This paragraph provides requirements for powerplant instruments, especially fuel flow and oil-related instruments.</p> <p>Rationale: Monitoring of some powerplant systems may be necessary to avoid explosion hazards, so this paragraph was rolled up. Subparagraphs (a2), (d), and (e) are especially relevant.</p>	
Electrical Systems and Equipment			
§27.1351 General	Modified	<p>(a) Electrical system capacity. Electrical equipment <i>whose failure could adversely affect safety</i> must be adequate for its intended use. In addition—</p> <p>(1) Electric power sources, their transmission cables, and their associated control and protective devices must be able to furnish the required power at the proper voltage to each load circuit essential for safe operation; and</p> <p>(2) Compliance with paragraph (a)(1) of this section must be shown by an electrical load analysis, or by electrical measurements that take into account the electrical loads applied to the electrical system, in probable combinations and for probable durations.</p> <p>(b) Function. For each <i>safety-critical</i> electrical system, the following apply:</p> <p>(1) Each system, when installed, must be—</p> <p>(i) Free from hazards in itself, in its method of operation, and in its effects on other parts of the rotorcraft; and</p> <p>(ii) Protected from fuel, oil, water, other</p>	<p>Rationale: Loss of electrical power does not necessarily lead to a hazardous event. Proper functioning of the electrical system is only required on the parts of the system needed to maintain safety (e.g., the independent power source for the containment system needs to meet this requirement).</p>



		<p>detrimental substances, and mechanical damage.</p> <p>(2) Electric power sources must function properly when connected in combination or independently.</p> <p>(3) No failure or malfunction of any source may impair the ability of any remaining source to supply load circuits essential for safe operation.</p> <p>(4) Each electric power source control must allow the independent operation of each source.</p> <p><del>(c) <i>Generating system.</i> There must be at least one generator if the system supplies power to load circuits essential for safe operation. In addition—</del></p> <p><del>(1) Each generator must be able to deliver its continuous rated power;—</del></p> <p><del>(2) Generator voltage control equipment must be able to dependably regulate each generator output within rated limits;—</del></p> <p><del>(3) Each generator must have a reverse-current cutout designed to disconnect the generator from the battery and from the other generators when enough reverse-current exists to damage that generator;— and—</del></p> <p><del>(4) Each generator must have an overvoltage control designed and installed to prevent damage to the electrical system, or to equipment supplied by the electrical system, that could result if that generator were to develop an overvoltage condition.—</del></p> <p>(d) Instruments. There must be means to indicate to appropriate crewmembers the electric power system quantities essential for safe operation of the system. In addition—</p> <p>(1) For direct current systems, an ammeter that can be switched into each generator feeder may be used; and</p> <p>(2) If there is only one generator, the ammeter may be in the battery feeder.</p> <p>(e) External power. If provisions are made for connecting external power to the rotorcraft, and that external power can be electrically connected to equipment other than that used for engine starting, means must be provided to ensure that no external power supply having a reverse polarity, or a reverse phase sequence, can supply power to the rotorcraft's electrical system.</p>	
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<p>§27.1353 Storage battery design and installation</p>	<p>Modified</p>	<p><i>For equipment whose failure could adversely safety:</i></p> <p>(a) Each storage battery must be designed and installed as prescribed in this section.</p> <p>(b) Safe cell temperatures and pressures must be maintained during any probable charging and discharging condition. No uncontrolled increase in cell temperature may result when the battery is recharged (after previous complete discharge)—</p> <p>(1) At maximum regulated voltage or power;</p> <p>(2) During a flight of maximum duration; and</p> <p>(3) Under the most adverse cooling condition likely to occur in service.</p> <p>(c) Compliance with paragraph (b) of this section must be shown by test unless experience with similar batteries and installations has shown that maintaining safe cell temperatures and pressures presents no problem.</p> <p>(d) No explosive or toxic gases emitted by any battery in normal operation, or as the result of any probable malfunction in the charging system or battery installation, may accumulate in hazardous quantities within the rotorcraft.</p> <p>(e) No corrosive fluids or gases that may escape from the battery may damage surrounding structures or adjacent essential equipment.</p> <p>(f) Each nickel cadmium battery installation capable of being used to start an engine or auxiliary power unit must have provisions to prevent any hazardous effect on structure or essential systems that may be caused by the maximum amount of heat the battery can generate during a short circuit of the battery or of its individual cells.</p> <p>(g) Nickel cadmium battery installations capable of being used to start an engine or auxiliary power unit must have—</p> <p>(1) A system to control the charging rate of the battery automatically so as to prevent battery overheating;</p> <p>(2) A battery temperature sensing and over-temperature warning system with a means for disconnecting the battery from its charging source in the event of an over-temperature condition; or</p> <p>(3) A battery failure sensing and warning system with a means for disconnecting the</p>	<p>Rationale: Loss of battery power does not necessarily lead to any identified hazard. Therefore proper functioning of the batteries is only required where the battery supplies the parts of the system needed to maintain safety (e.g., the containment system).</p>
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		battery from its charging source in the event of battery failure.	
§27.1357 Circuit protective devices	Modified	<p><i>For equipment whose failure could adversely affect safety:</i></p> <p>(a) Protective devices, such as fuses or circuit breakers, must be installed in each electrical circuit other than—</p> <p>(1) The main circuits of starter motors; and</p> <p>(2) Circuits in which no hazard is presented by <del>their</del> <i>the</i> omission <i>of protective devices</i>.</p> <p>(b) A protective device for a circuit essential to flight safety may not be used to protect any other circuit.</p> <p>(c) Each resettable circuit protective device (“trip free” device in which the tripping mechanism cannot be overridden by the operating control) must be designed so that—</p> <p>(1) A manual operation is required to restore service after tripping <i>[sic]</i>; and</p> <p>(2) If an overload or circuit fault exists, the device will open the circuit regardless of the position of the operating control.</p> <p>(d) If the ability to reset a circuit breaker or replace a fuse is essential to safety in flight, that circuit breaker or fuse must be located and identified so that it can be readily reset or replaced in flight.</p> <p>(e) If fuses are used, there must be one spare of each rating, or 50 percent spare fuses of each rating, whichever is greater.</p>	Rationale: This change is strictly unnecessary given the caveat in subparagraph (a)(2). However, this change emphasizes the point that only systems that can create hazards must include such protective devices.
§27.1361 Master switch	Modified	<p><i>For equipment whose failure could adversely affect safety:</i></p> <p>(a) There must be a master switch arrangement to allow ready disconnection of each electric power source from the main bus. The point of disconnection must be adjacent to the sources controlled by the switch.</p> <p>(b) Load circuits may be connected so that they remain energized after the switch is opened, if they are protected by circuit protective devices, rated at five amperes or less, adjacent to the electric power source.</p> <p>(c) The master switch or its controls must be installed so that the switch is easily discernible and accessible to a crewmember <del>in flight</del>.</p>	Rationale: A master switch is necessary to ensure the safety of crewmembers before takeoff and after landing.
§27.1365 Electric cables	Modified	<p><i>For equipment whose failure could adversely affect safety:</i></p> <p>(a) Each electric connecting cable must be of adequate capacity.</p> <p>(b) Each cable that would overheat in the</p>	Rationale: Electrical cable failure (e.g., short circuit, open circuit) does not necessarily lead to any identified hazard. Therefore proper functioning of the electrical cables is only required on the

		event of circuit overload or fault must be at least flame resistant and may not emit dangerous quantities of toxic fumes. (c) Insulation on electrical wire and cable installed in the rotorcraft must be self-extinguishing when tested <del>in accordance with appendix F, part I(a)(3), of part 25 of this chapter.</del>	parts of the system needed to maintain safety.
§27.1367 Switches	Modified	<i>For equipment whose failure could adversely affect safety:</i> Each switch must be— (a) Able to carry its rated current; (b) Accessible to the crew; and (c) Labeled as to operation and the circuit controlled.	Rationale: Proper functioning of safety-relevant switches is necessary to ensure the safety of crewmembers before takeoff and after landing.
Lights			
§27.1381 Instrument lights	Modified	<del>The instrument lights</del> <i>For each display or other presentation of data required for systems whose failure adversely affects safety, that display or presentation must—</i> (a) Make each <del>instrument, switch, and other devices for which they are provided</del> <i>relevant device, display, or presentation</i> easily readable; and (b) Be installed so that— (1) <del>Their direct rays are shielded from the pilot's eyes; and</del> (2) <del>No</del> objectionable reflections <i>or illumination levels render required data unintelligible to the pilot in normal operations</i> <del>are visible to the pilot</del>	Rationale: In general, the instruments (displays) in the ground control station will provide their own lighting. Instrument lights in a cockpit are required for the pilot to perform safety-related tasks.
§27.1383 Landing lights — <i>and supplemental lighting for night operations</i>	Modified	<del>(a) Each required landing or hovering light</del> <i>landing or hovering light or supplemental ground or airborne required for approved night rotorcraft operations</i> must be approved. <del>(b) Each landing light must be installed so that—</del> (1) <del>No objectionable glare is visible to the pilot;</del> (2) <del>The pilot is not adversely affected by halation; and</del> (3) <del>It provides enough light for night operation, including hovering and landing.</del> <del>(c) At least one separate switch must be provided, as applicable—</del> (1) <del>For each separately installed landing light; and</del> (2) <del>For each group of landing lights installed at a common location.</del>	Rationale: This requirement was reworded since landing lights may not be located only on the rotorcraft, but may be provided by ground support equipment.

§27.1385 Position light system installation	Excluded	<p>Summary: This paragraph provides position light requirements.</p> <p>Rationale: Out of ConOps scope. Mitigated by other regulation. Per the ConOps, the unmanned rotorcraft will yield right-of-way. Due to the reduced size of the vehicle (compared with Part 27 rotorcraft), use of position lights may not enhance situational awareness for pilots of other aircraft.</p>	
§27.1387 Position light system dihedral angles.	Excluded	<p>Summary: This paragraph provides requirements specific to the dihedral angle of the position lights.</p> <p>Rationale: Out of ConOps scope. Secondary hazard. Per the ConOps, the unmanned rotorcraft will yield right-of-way. Due to the reduced size of the vehicle (compared with Part 27 rotorcraft), use of position lights may not enhance situational awareness for pilots of other aircraft.</p>	
§27.1389 Position light distribution and intensities	Excluded	<p>Summary: This paragraph provides requirements specific to the intensities of position lights.</p> <p>Rationale: Out of ConOps scope. Secondary hazard. Per the ConOps, the unmanned rotorcraft will yield right-of-way. Due to the reduced size of the vehicle (compared with Part 27 rotorcraft), use of position lights may not enhance situational awareness for pilots of other aircraft.</p>	
§27.1391 Minimum intensities in the horizontal plane of forward and rear position lights	Excluded	<p>Summary: This paragraph sets minimum requirements for position light intensities in the horizontal plane.</p> <p>Rationale: Out of ConOps scope. Secondary hazard. Per the ConOps, the unmanned rotorcraft will yield right-of-way. Due to the reduced size of the vehicle (compared with Part 27 rotorcraft), use of position lights may not enhance situational awareness for pilots of other aircraft.</p>	
§27.1393 Minimum intensities in any vertical plane of forward and rear position lights	Excluded	<p>Summary: This paragraph sets minimum requirements for position light intensities in the vertical plane.</p> <p>Rationale: Out of ConOps scope. Secondary hazard. Per the ConOps, the unmanned rotorcraft will yield right-of-way. Due to the reduced size of the vehicle (compared with Part 27 rotorcraft), use of position lights may not enhance situational awareness for pilots of other aircraft.</p>	
§27.1395 Maximum intensities in overlapping beams of forward and rear position lights	Excluded	<p>Summary: This paragraph sets maximum intensities for position lights.</p> <p>Rationale: Out of ConOps scope. Secondary hazard. Per the ConOps, the unmanned rotorcraft will yield right-of-way. Due to the reduced size of the vehicle (compared with Part 27 rotorcraft), use of position lights may not enhance situational awareness for pilots of other aircraft.</p>	
§27.1397 Color specifications	As is	<p>Each position light color must have the applicable International Commission on Illumination chromaticity coordinates as follows:</p> <p>(a) Aviation red— y is not greater than 0.335; and z is not greater than 0.002.</p> <p>(b) Aviation green— x is not greater than 0.440–0.320y; x is not greater than y–0.170; and</p>	<p>Rationale: These requirements are maintained to ensure compatibility with the expected colors by other airspace users.</p>

		<p><math>y</math> is not less than <math>0.390-0.170x</math>.</p> <p>(c) Aviation white—</p> <p><math>x</math> is not less than 0.300 and not greater than 0.540;</p> <p><math>y</math> is not less than <math>x-0.040</math>” or <math>y_c-0.010</math>, whichever is the smaller; and</p> <p><math>y</math> is not greater than <math>x+0.020</math> nor <math>0.636-0.400x</math>;</p> <p>Where <math>y_c</math> is the <math>y</math> coordinate of the Planckian radiator for the value of <math>x</math> considered.</p>	
§27.1399 Riding light	Excluded	<p>Summary: This paragraph provides requirements for riding lights (used in water applications).</p> <p>Rationale: Out of ConOps scope. Water operations are not part of the ConOps.</p>	
§27.1401 Anticollision light system	Modified	<p>(a) General. If certification for night operation is requested, the rotorcraft must have an anticollision light system that—</p> <p>(1) Consists of one or more approved anticollision lights located so that their emitted light will not impair the crew's vision or detract from the conspicuity of the position lights; and</p> <p>(2) Meets the requirements of paragraphs (b) through (f) of this section.</p> <p>(b) Field of coverage. The system must consist of enough lights to illuminate the vital areas around the rotorcraft, considering the physical configuration and flight characteristics of the rotorcraft. The field of coverage must extend in each direction within at least 30 degrees below the horizontal plane of the rotorcraft, except that there may be solid angles of obstructed visibility totaling not more than 0.5 steradians.</p> <p>(c) Flashing characteristics. The arrangement of the system, that is, the number of light sources, beam width, speed of rotation, and other characteristics, must give an effective flash frequency of not less than 40, nor more than 100, cycles per minute. The effective flash frequency is the frequency at which the rotorcraft's complete anticollision light system is observed from a distance, and applies to each sector of light including any overlaps that exist when the system consists of more than one light source. In overlaps, flash frequencies may exceed 100, but not 180, cycles per minute.</p> <p>(d) Color. Each anticollision light must be aviation red and must meet the applicable requirements of §27.1397.</p>	<p>Rationale: A small addition was made to this requirement in subparagraph (g) to emphasize that the pilot must be able to turn off the anti-collision lights to ensure other crewmembers can perform their safety role during takeoffs and landings.</p>

	<p>(e) Light intensity. The minimum light intensities in any vertical plane, measured with the red filter (if used) and expressed in terms of “effective” intensities, must meet the requirements of paragraph (f) of this section. The following relation must be assumed:</p> $I_e = \frac{\int_{t_1}^{t_2} I(t) dt}{0.2 + (t_2 - t_1)}$ <p>View or download PDF</p> <p>where:</p> <p>I<sub>e</sub>=effective intensity (candles).</p> <p>I(t)=instantaneous intensity as a function of time.</p> <p>t<sub>2</sub>–t<sub>1</sub>=flash time interval (seconds).</p> <p>Normally, the maximum value of effective intensity is obtained when t<sub>2</sub> and t<sub>1</sub> are chosen so that the effective intensity is equal to the instantaneous intensity at t<sub>2</sub> and t<sub>1</sub>.</p> <p>(f) Minimum effective intensities for anticollision light. Each anticollision light effective intensity must equal or exceed the applicable values in the following table:</p> <table><tr><th>Angle above or below the horizontal plane</th><th>Effective intensity (candles)</th></tr><tr><td>0° to 5°</td><td>150</td></tr><tr><td>5° to 10°</td><td>90</td></tr><tr><td>10° to 20°</td><td>30</td></tr><tr><td>20° to 30°</td><td>15</td></tr></table> <p>(g) <i>A means must be provided for the pilot to deactivate the anticollision lights in any flight phase.</i></p>	Angle above or below the horizontal plane	Effective intensity (candles)	0° to 5°	150	5° to 10°	90	10° to 20°	30	20° to 30°	15	
Angle above or below the horizontal plane	Effective intensity (candles)											
0° to 5°	150											
5° to 10°	90											
10° to 20°	30											
20° to 30°	15											

Safety Equipment			
§27.1411 General	Modified	<p>(a) Required safety equipment to be used by the crew in an emergency; <del>such as flares and automatic liferaft releases,</del> must be readily accessible.</p> <p><del>(b) Stowage provisions for required safety equipment must be furnished and must —</del></p> <p><del>(1) Be arranged so that the equipment is directly accessible and its location is obvious; and</del></p> <p><del>(2) Protect the safety equipment from</del></p>	<p>Rationale: The particular examples of safety equipment may not be relevant for unmanned rotorcraft operations; however, the pilot and other crewmembers may need some safety equipment (e.g., fire extinguishers) that must be readily available.</p>

		<del>damage caused by being subjected to the inertia loads specified in §27.561.</del>	
§27.1413 Safety belts	Excluded	Summary: This paragraph requires seat belts to have a metal latching device. Rationale: Does not map to a hazard.	
§27.1415 Ditching equipment	Excluded	Summary: This paragraph provides requirements for ditching equipment (e.g., life rafts). Rationale: Does not map to a hazard.	
§27.1419 Ice protection	Excluded	Summary: This paragraph provides requirements for operation in icing conditions. Rationale: Out of ConOps scope.	
§27.1435 Hydraulic systems	Excluded	Summary: This paragraph provides requirements for design, test, and installation of hydraulic equipment. Rationale: Does not map to a hazard. Ejection of high energy parts from a rupture of the hydraulic system was considered sufficiently inconsequential.	
§27.1457 Cockpit voice recorders	Excluded	Summary: This paragraph provides requirements for cockpit voice recorders. Rationale: It is not clear what cockpit (or ground control station) voice recording would serve. The expectation is that accident investigation (if necessary) will not need voice recordings. Flight data (as per §27.1459) is assumed to be more relevant for determining accident cause.	
§27.1459 Flight data recorders	Modified	<p><del>(a) Each flight recorder required by the operating <i>approval associated with the vehicle specified in this type design must meet the data recording requirements specified by the Administrator.</i> rules of Subchapter G of this chapter must be installed so that:</del></p> <p><del>(1) It is supplied with airspeed, altitude, and directional data obtained from sources that meet the accuracy requirements of §27.1323, §27.1325, and §27.1327 of this part, as applicable;</del></p> <p><del>(2) The vertical acceleration sensor is rigidly attached, and located longitudinally within the approved center of gravity limits of the rotorcraft;</del></p> <p><del>(3)(i) It receives its electrical power from the bus that provides the maximum reliability for operation of the flight data recorder without jeopardizing service to essential or emergency loads.</del></p> <p><del>(ii) It remains powered for as long as possible without jeopardizing emergency operation of the rotorcraft.</del></p> <p><del>(4) There is an aural or visual means for preflight checking of the recorder for proper recording of data in the storage medium;</del></p> <p><del>(5) Except for recorders powered solely by the engine driven electrical generator system, there is an automatic means to simultaneously stop a recorder that has a data erasure feature and prevent each</del></p>	<p>Rationale: It is not clear exactly what purpose a flight data recorder would serve for an unmanned rotorcraft, nor is it clear that an unmanned aircraft needs the detailed survivability requirements as described in this paragraph. The ground control station may provide all necessary data recording. The language was changed to allow more generic requirements for data recording.</p>



		<p>erasure feature from functioning, within 10 minutes after any crash impact; and</p> <p><del>(6) Whether the cockpit voice recorder and digital flight data recorder are installed in separate boxes or in a combination unit, no single electrical failure external to the recorder may disable both the cockpit voice recorder and the digital flight data recorder.</del></p> <p><del>(b) Each nonejectable recorder container must be located and mounted so as to minimize the probability of container rupture resulting from crash impact and subsequent damage to the record from fire.</del></p> <p><del>(c) A correlation must be established between the flight recorder readings of airspeed, altitude, and heading and the corresponding readings (taking into account correction factors) of the first pilot's instruments. This correlation must cover the airspeed range over which the aircraft is to be operated, the range of altitude to which the aircraft is limited, and 360 degrees of heading. Correlation may be established on the ground as appropriate.</del></p> <p><del>(d) Each recorder container must:</del></p> <p><del>(1) Be either bright orange or bright yellow;</del></p> <p><del>(2) Have a reflective tape affixed to its external surface to facilitate its location under water; and</del></p> <p><del>(3) Have an underwater locating device, when required by the operating rules of this chapter, on or adjacent to the container which is secured in such a manner that they are not likely to be separated during crash impact.</del></p> <p><del>(e) When both a cockpit voice recorder and a flight data recorder are required by the operating rules, one combination unit may be installed, provided that all other requirements of this section and the requirements for cockpit voice recorders under this part are met.</del></p>	
§27.1461 Equipment containing high energy rotors	Modified	<p>(a) Equipment <i>whose failure adversely affects safety and</i> contains high energy rotors must meet paragraph (b), (c), or (d) of this section.</p> <p>(b) High energy rotors contained in equipment must be able to withstand damage caused by malfunctions, vibration, abnormal speeds, and abnormal temperatures. In addition—</p>	Rationale: The requirement was rewritten to emphasize that not all equipment with high-energy rotors that fails is capable of causing harm. Furthermore, this requirement recognizes that non-engine related components might contain high-energy rotors.

		<p>(1) Auxiliary rotor cases must be able to contain damage <i>relevant to Paragraph (a) of this section and</i> caused by the failure of high energy rotor blades; and</p> <p>(2) Equipment control devices, systems, and instrumentation must reasonably ensure that no operating limitations affecting the integrity of high energy rotors will be exceeded in service.</p> <p>(c) It must be shown by test that equipment containing high energy rotors can, <i>without directly causing one or more of the failure conditions addressed in Paragraph (a) of this section</i>, contain any failure of a high energy rotor that occurs at the highest speed obtainable with the normal speed control devices inoperative.</p> <p>(d) Equipment containing high energy rotors must be located where rotor failure will <del>neither endanger the occupants nor</del> <i>not</i> adversely affect continued safe flight.</p>	
<b>Subpart G—Operating Limitations and Information</b>			
§27.1501 General	Modified	<p><del>(a) Each operating limitation <i>required by the Administrator</i> specified in §27.1503 through §27.1525 and other limitations and information necessary for safe operation must be established <i>and</i></del></p> <p><del>(b) The operating limitations and other information necessary for safe operation must be made available to the crewmembers as prescribed in §27.1541 through §27.1589.</del></p>	Rationale: References to specific subparagraphs that specify operating limitations for Part 27 rotorcraft were deleted because operating limitations relevant to an unmanned rotorcraft operating in a confined area have not yet been established. The reference was changed to a more general reference to operating limitations established by the FAA Administrator. Those operating limitations should still be made available to crewmembers.
<b>Operating Limitations</b>			
§27.1503 Airspeed limitations: general	Excluded	<p>Summary: This paragraph requires identifying an operating speed range, especially for establishing speed limitations.</p> <p>Rationale: Does not map to a hazard. Operating at the UA's speed limitations is not directly linked to a hazard, so it is necessary to know what the limits are. For the most part, operating at the speed limits is not likely under the ConOps.</p>	
§27.1505 Never-exceed speed	Excluded	<p>Summary: This paragraph establishes conditions on the never-exceed speed.</p> <p>Rationale: Does not map to a hazard. It is not necessary to establish a never-exceed speed related to the structural limits of the vehicle, because exceeding that limit does not map directly to a hazard.</p>	
§27.1509 Rotor speed	Rolled up to SI	<p>Summary: This paragraph establishes ranges of values for maximum and minimum rotor speeds under power-off and power-on conditions.</p> <p>Rationale: While maximum and minimum rotor speeds are clearly related to maintaining rotor system integrity, it is not known whether the specific ranges required for manned rotorcraft are directly applicable to an unmanned rotorcraft with different risk profiles. The paragraph was relegated to the rollup where the applicant and the regulator could determine the appropriate ranges of values.</p>	

§27.1519 Weight and center of gravity	Rolled up to CMS(a)	Summary: This paragraph requires that weight and center of gravity limitations be established. Rationale: Since these are critical parameters affecting controllability and maneuverability, this requirement was added to the CMS rollup.	
§27.1521 Powerplant limitations	Rolled up to PPS	Summary: This paragraph specifies a requirement to establish relevant powerplant limitations, such as torque, temperature, speed, and other parameters, under a variety of conditions and for various time limits. Rationale: The requirement to establish powerplant limitations was considered relevant to protecting rotor system integrity, but the specific conditions and times were considered too detailed. So, the general requirement for powerplant limitations was retained but rolled up into the more general language of the issue paper.	
§27.1523 Minimum <del>flight</del> crew	Modified	The minimum <del>flight</del> crew must be established so that it is sufficient for safe operation, considering— (a) The workload on <i>and safety roles of</i> individual crewmembers; <i>and</i> (b) <del>The accessibility and ease of operation of necessary controls by the appropriate crewmember; and</del> (c) The kinds of operation authorized under §27.1525.	Rationale: The word “flight” was deleted as a modifier to crew, since it is not appropriate for UAS (given the definition of crew). Wording was added in subparagraph (a) to include consideration of the crew’s safety role in determining the minimum size of the UAS crew. Words related to accessibility and ease of operation of controls were deleted in subparagraph (b), assuming that the original text referred to the accessibility of onboard controls to onboard crew, and that more general language about workload is desired because accessibility and ease of operation are only 2 of a larger set of attributes that affect the crew’s ability to perform their safety role.
§27.1525 Kinds of operations	Modified	The kinds of operations (such as VFR, IFR, day, night, or icing) for which the <del>rotorcraft</del> <i>UAS</i> is approved are established by demonstrated compliance with the applicable certification requirements and by the installed equipment.	Rationale: The approved operation includes capabilities of the whole UA system, including the vehicle, the ground control station, datalinks, etc.
§27.1527 Maximum operating altitude	Modified	The maximum altitude up to which operation is allowed, as limited by flight, structural, powerplant, functional, <i>safety</i> , or equipment characteristics, must be established.	Rationale: The word “safety” was added to the list of considerations for establishing maximum altitude because operating limitations on altitude are an explicit limitation on the operation to help mitigate safety concerns when operating at altitudes where air traffic is expected (e.g., above 500 ft).
§27.1529 Instructions for Continued Airworthiness	Modified	The applicant must prepare Instructions for Continued Airworthiness in accordance with <i>this G-1U issue paper, Appendix A to this part</i> that are acceptable to the Administrator. <del>The</del> <i>Instructions</i> may be incomplete at type certification if a program exists to ensure their completion prior to delivery of the first rotorcraft or issuance of a standard certificate of airworthiness, whichever occurs later.	Rationale: Instructions for continued airworthiness are applicable. Editorial changes were made to make it clear that the relevant instructions for continued airworthiness are those specified in the G-1U issue paper.

Markings and Placards			
§27.1541 General	Modified	<p>(a) The <del>rotorcraft</del> <i>UAS</i> must contain—</p> <p>(1) The markings and placards specified <i>in this G-1U Issue Paper §27.1545 through §27.1565</i>, and</p> <p>(2) Any additional information, instrument markings, and placards required for the safe operation of <del>rotorcraft</del> <i>UAS</i> with unusual design, operating or handling characteristics.</p> <p>(b) Each marking and placard prescribed in paragraph (a) of this section—</p> <p>(1) Must be displayed in a conspicuous place; and</p> <p>(2) May not be easily erased, disfigured, or obscured.</p>	<p>Rationale: In (a), “rotorcraft” was changed to “UAS” (in 2 places) because markings and placards may be located in the ground control station or on other equipment in addition to the rotorcraft. A UAS may need markings and placards for safe operation that are not usually needed for manned rotorcraft (e.g., markings for landing zone of vehicle).</p> <p>References to specific paragraphs that specify markings and placards in (1) were deleted in favor of a more general reference to the requirements for markings and placards identified in this G-1U Issue Paper (e.g., 27.1557, any of the special issue papers, etc.).</p>
§27.1543 Instrument markings: general	Excluded	<p>Summary: This paragraph addresses alignment of markings on cockpit instruments that have glass covers.</p> <p>Rationale: Does not map to a hazard. Not UAS relevant. Instruments with glass covers (like those found in a cockpit) are not expected in a UAS ground control station.</p>	
§27.1545 Airspeed indicator	Excluded	<p>Summary: This paragraph describes the markings necessary on an airspeed indicator.</p> <p>Rationale: The requirements for an airspeed indicator was excluded, so requirements for markings are not needed.</p>	
§27.1547 Magnetic direction indicator	Excluded	<p>Summary: This paragraph describes placards necessary for magnetic direction indicators.</p> <p>Rationale: The requirements for a magnetic direction indicator was excluded, so requirements for placards are not needed.</p>	
§27.1549 Powerplant instruments	Excluded	<p>Summary: This paragraph specifies required markings on powerplant instruments.</p> <p>Rationale: The requirements for powerplant instruments were excluded, so requirements for markings are not needed</p>	
§27.1551 Oil quantity indicator	Excluded	<p>Summary: This paragraph requires markings on oil quantity indicators.</p> <p>Rationale: The requirements for an oil quantity indicator were excluded, so requirements for markings are not needed.</p>	
§27.1553 Fuel quantity indicator	Excluded	<p>Summary: This paragraph specifies requirements for markings relative to unusable fuel level.</p> <p>Rationale: The requirements for a fuel quantity indicator were excluded, so requirements for markings are not needed.</p>	
§27.1555 Control markings	Modified	<p><del>(a) Each cockpit control, other than primary flight controls or control whose function is obvious, must be plainly marked as to its function and method of operation.</del></p> <p><del>(b) For powerplant fuel controls—</del></p> <p><del>(1) Each fuel tank selector control must be marked to indicate the position corresponding to each tank and to each existing cross feed position;</del></p> <p><del>(2) If safe operation requires the use of any tanks in a specific sequence, that sequence</del></p>	<p>Rationale: Requirements for controls, as described in this paragraph, have been excluded because the pilot does not have inner-loop control. However, subparagraph (d)(2) for marking emergency controls in red applies to emergency controls that the pilot would use to cause the rotorcraft to hover or land in emergency situations.</p>

		<p>must be marked on, or adjacent to, the selector for those tanks; and</p> <p>(3) Each valve control for any engine of a multiengine rotorcraft must be marked to indicate the position corresponding to each engine controlled.</p> <p>(c) Usable fuel capacity must be marked as follows:</p> <p>(1) For fuel systems having no selector controls, the usable fuel capacity of the system must be indicated at the fuel quantity indicator.</p> <p>(2) For fuel systems having selector controls, the usable fuel capacity available at each selector control position must be indicated near the selector control.</p> <p>(d) For accessory, auxiliary, and emergency controls —</p> <p>(1) Each essential visual position indicator, such as those showing rotor pitch or landing gear position, must be marked so that each crewmember can determine at any time the position of the unit to which it relates; and</p> <p>(2) Each emergency control must be red and must be marked as to method of operation.</p> <p>(e) For rotorcraft incorporating retractable landing gear, the maximum landing gear operating speed must be displayed in clear view of the pilot.</p>	
§27.1557 Miscellaneous markings and placards	Modified	<p>(a) <del>Baggage</del><i>Payload</i>, and cargo compartments, and ballast location. Each <del>baggage and cargo</del> <i>payload</i> compartment, and each ballast location must have a placard stating any limitations on contents, including weight, that are necessary under the loading requirements.</p> <p>(b) <del>Seats. If the maximum allowable weight to be carried in a seat is less than 170 pounds, a placard stating the lesser weight must be permanently attached to the seat structure.</del></p> <p>(c) Fuel and oil filler openings. The following apply:</p> <p>(1) Fuel filler openings must be marked at or near the filler cover with—</p> <p>(i) The word “fuel”;</p> <p>(ii) <del>For reciprocating engine powered rotorcraft, the minimum fuel grade;</del></p> <p>(iii) For turbine engine powered rotorcraft, the permissible fuel designations; and</p> <p>(iv) For pressure fueling systems, the</p>	<p>Rationale: “Baggage” and “cargo” were replaced in subparagraph (a) with “payload” because the UAS in an agricultural concept of operations is not intended to convey baggage or cargo, but will convey payload, such as agricultural chemicals or cameras or sensors for surveying fields.</p> <p>Subparagraph (b) was deleted because seats are not needed aboard the UAS. Any seats in the ground control station are not considered critical to safety of flight.</p> <p>Subparagraph (c, 1, ii) was deleted because this G-1U was not intended to apply to rotorcraft with piston engines</p> <p>Subparagraph (d) was deleted because there are no people on board the UAS, hence there is no need for emergency exit placards on the rotorcraft. We are assuming that OSHA requirements would necessitate exit placards for any indoor areas of a ground control station.</p>

		<p>maximum permissible fueling supply pressure and the maximum permissible defueling pressure.</p> <p>(2) Oil filler openings must be marked at or near the filler cover with the word “oil”.</p> <p><del>(d) Emergency exit placards. Each placard and operating control for each emergency exit must be red. A placard must be near each emergency exit control and must clearly indicate the location of that exit and its method of operation.</del></p>	
§27.1559 Limitations placard	Modified	<p>There must be a placard in clear view of the pilot that specifies the kinds of operations (such as <i>visual line-of-sight</i>, <i>beyond visual line-of-sight</i>, VFR, IFR, day, night, or icing) for which the <i>UAS rotorcraft</i> is approved.</p>	<p>Rationale: Visual line-of-sight and beyond line-of-sight operations are different from typical operations for Part 27 rotorcraft. They were added to the list of example operations because it is important for a UAS pilot to be aware of the sight-line limitations for approved UAS operations.</p>
§27.1561 Safety equipment	Modified	<p>(a) Each <i>required</i> safety equipment control to be operated by the crew in emergency, <del>such as controls for automatic liferaft releases,</del> must be plainly marked as to its method of operation.</p> <p>(b) Each location, such as a locker or compartment, that carries any fire extinguishing, signaling, or other life saving equipment, must be so marked.</p>	<p>Rationale: The example of life rafts as safety equipment was deleted since there is no need for life rafts on UAS. The word “required” was added to safety equipment to indicate that not all safety equipment for a UAS may necessarily be considered required (e.g., a fire extinguisher in the ground control station should not need a placard). If it is required, it should be marked appropriately.</p>
§27.1565 Tail Rotor	As is	Each tail rotor must be marked so that its disc is conspicuous under normal daylight ground conditions.	<p>Rationale: If the unmanned rotorcraft has a tail rotor, then it should be marked as described.</p>
Rotorcraft Flight Manual and Approved Manual Material			
§27.1581 General	Modified	<p>(a) Furnishing information. A Rotorcraft Flight Manual must be furnished with each rotorcraft, and it must contain the following:</p> <p>(1) Information required <i>for UAS functions whose failure could adversely affect safety, and by §27.1583 through §27.1589.</i></p> <p>(2) Other information that is necessary for safe operation because of design, operating, or handling characteristics.</p> <p>(b) Approved information. Each part of the manual <del>listed in §27.1583 through §27.1589, that is appropriate to the rotorcraft, must be</del> furnished, verified, and approved <i>under its associated type certificate,</i> <del>and</del> must be segregated, identified, and clearly distinguished from each unapproved part of that manual.</p> <p>(c) [Reserved]</p>	<p>Rationale: A flight manual is important. References to Part 27 paragraphs specifying content of the flight manual were replaced with a more general requirement that the flight manual should provide information on safety-critical functions. Not all of the original paragraphs referenced were considered applicable to this issue paper.</p>

		(d) Table of contents. Each Rotorcraft Flight Manual must include a table of contents if the complexity of the manual indicates a need for it.	
§27.1583 Operating Limitations	Modified	<p><i>A Rotorcraft Flight Manual must contain operating limitations for each of the following, as relevant to safety-critical functions, including, but not limited to:</i></p> <p>(a) <del>Airspeed and rotor limitations. Information necessary for the marking of airspeed and rotor limitations on, or near, their respective indicators,</del> must be furnished. The significance of each limitation <del>and of the color coding</del> must be explained.</p> <p>(b) Powerplant limitations. The following information must be furnished:</p> <p>(1) Limitations <i>necessary to maintain powerplant integrity</i> <del>required by §27.1521.</del></p> <p>(2) Explanation of the limitations, when appropriate.</p> <p>(3) <del>Information necessary for marking the instruments, required by §§27.1549 through 27.1553.</del></p> <p>(c) Weight and loading distribution. The weight and center of gravity limits <del>required by §§27.25 and 27.27, respectively,</del> must be furnished. If the variety of possible loading conditions warrants, instructions must be included to allow ready observance of the limitations <i>specifically for takeoffs.</i></p> <p>(d) <del>Flight</del> UAS crew. When a <del>flight</del> crew of more than one is required, the number and functions of the minimum <del>flight</del> crew determined under §27.1523 must be furnished.</p> <p>(e) Kinds of operation. Each kind of operation for which the rotorcraft and its equipment installations are approved must be listed.</p> <p>(f) [Reserved]</p> <p>(g) Altitude. The altitude established under §27.1527 and an explanation of the limiting factors must be furnished.</p>	<p>Rationale: Operating limitations should be documented in the flight manual. Modifications were made to generalize some of the requirements and delete references to Part 27 requirements that were not included in this issue paper.</p>
§27.1585 Operating procedures	Modified	(a) Parts of the manual containing operating procedures must have information concerning any normal and emergency procedures and other information necessary for safe operation, including takeoff and landing procedures and associated airspeeds. The manual must contain any pertinent information	<p>Rationale: Subparagraph (a) was kept because the kind of information specified is relevant.</p> <p>Subparagraph (b) was deleted because multiengine rotorcraft were considered beyond the scope of the issue paper.</p> <p>In subparagraph (c), the reference to §27.1505(c) (for a stabilized power-off</p>



		<p>including—</p> <p>(1) The kind of takeoff surface used in the tests and each appropriate climbout speed; and</p> <p>(2) The kind of landing surface used in the tests and appropriate approach and glide airspeeds.</p> <p><del>(b) For multiengine rotorcraft, information identifying each operating condition in which the fuel system independence prescribed in §27.953 is necessary for safety must be furnished, together with instructions for placing the fuel system in a configuration used to show compliance with that section.</del></p> <p>(c) For helicopters for which a <math>V_{NE}</math> (power-off) is established under <i>this G-1U Issue Paper</i> §27.1505(e), information must be furnished to explain the <math>V_{NE}</math> (power-off) and the procedures for reducing airspeed to not more than the <math>V_{NE}</math> (power-off) following failure of <del>all</del> <i>the</i> engines.</p> <p>(d) For each rotorcraft showing compliance with §27.1353 (g)(2) or (g)(3), the operating procedures for disconnecting the battery from its charging source must be furnished.</p> <p>(e) If the unusable fuel supply in any tank exceeds five percent of the tank capacity, or one gallon, whichever is greater, information must be furnished which indicates that when the fuel quantity indicator reads “zero” in level flight, any fuel remaining in the fuel tank cannot be used safely in flight.</p> <p>(f) Information on the total quantity of usable fuel for each fuel tank must be furnished.</p> <p>(g) The airspeeds and rotor speeds for minimum rate of descent and best glide angle <del>as prescribed in §27.71</del> must be provided.</p>	<p><math>V_{NE}</math>) was deleted because it is not included in this G-1U Issue Paper. The vehicle’s ability to hold together under high speed conditions is not relevant to the concept of operations.</p> <p>In subparagraph (g), the reference to §27.71 (Autorotation performance) was deleted because there is no mandated requirement for autorotation. If autorotation is implemented, the airspeeds, rate of descent and glide angle curves are required.</p>
§27.1587 Performance information	Rolled up to CMS(a)	<p>Summary: This paragraph specifies that the flight manual must include enough information to determine the height-speed envelope relative to a number of different parameters. Other information required by the paragraph (e.g., the requirement to establish altitudes, temperatures, and winds at which the vehicle can be safely hovered) also relates to controllability and maneuverability.</p> <p>Rationale: Since the requirement to establish the height-speed envelope (§27.87) were rolled up to CMS(a), this paragraph was also rolled up.</p>	



§27.1589 Loading information	Rolled up to CMS(a)	Summary: This paragraph requires instructions to be included in the Flight Manual for all possible loading conditions that can cause the center of gravity to be exceeded. Rationale: Loading information is important to maintaining control margins that allow the vehicle to be safely controllable and maneuverable. This requirement is rolled up because only those loading conditions that affect controllability, maneuverability and stability needed to ensure rotor system integrity are needed.
<b>Appendix A—Instructions for Continued Airworthiness</b>		
A§27.1 General	Modified	<p>(a) This appendix specifies requirements for the preparation of Instructions for Continued Airworthiness as required by §27.1529.</p> <p>(b) The Instructions for Continued Airworthiness for each <del>UAS rotorcraft</del> must include the Instructions for Continued Airworthiness for each engine and rotor (hereinafter designated ‘products’), for each appliance required by this chapter, and any required information relating to the interface of those appliances and products with the <del>UAS rotorcraft</del>. If Instructions for Continued Airworthiness are not supplied by the manufacturer of an appliance or product installed in the <del>UAS rotorcraft</del>, the Instructions for Continued Airworthiness for the <del>UAS rotorcraft</del> must include the information essential to the continued airworthiness of the <del>UAS rotorcraft</del>.</p> <p>(c) The applicant must submit to the FAA a program to show how changes to the Instructions for Continued Airworthiness made by the applicant or by the manufacturers of products and appliances installed in the <del>UAS rotorcraft</del> will be distributed</p>
A§27.2 Format	As is	<p>(a) The Instructions for Continued Airworthiness must be in the form of a manual or manuals as appropriate for the quantity of data to be provided.</p> <p>(b) The format of the manual or manuals must provide for a practical arrangement.</p>
A§27.3 Content	Modified	<p>The contents of the manual or manuals must be prepared in the English language. The Instructions for Continued Airworthiness must contain the following manuals or sections, as appropriate, and information:</p> <p>(a) <del>UAS rotorcraft</del> maintenance manual or section.</p> <p>(1) Introduction information that includes an explanation of the <del>UAS’s rotorcraft</del> features and data to the extent necessary for maintenance or preventive</p>

		<p>maintenance.</p> <p>(2) A description of the <del>UAS rotorcraft</del> and its systems and installations including its engines, rotors, and appliances.</p> <p>(3) Basic control and operation information describing how the <del>UAS rotorcraft</del> components and systems are controlled and how they operate, including any special procedures and limitations that apply.</p> <p>(4) Servicing information that covers details regarding servicing points, capacities of tanks, reservoirs, types of fluids to be used, pressures applicable to the various systems, location of access panels for inspection and servicing, locations of lubrication points, the lubricants to be used, equipment required for servicing, tow instructions and limitations, mooring, jacking, and leveling information.</p> <p>(b) Maintenance instructions.</p> <p>(1) Scheduling information for each part of the <del>UAS rotorcraft</del> and its engines, auxiliary power units, rotors, accessories, instruments and equipment that provides the recommended periods at which they should be cleaned, inspected, adjusted, tested, and lubricated, and the degree of inspection, the applicable wear tolerances, and work recommended at these periods. However, the applicant may refer to an accessory, instrument, or equipment manufacturer as the source of this information if the applicant shows the item has an exceptionally high degree of complexity requiring specialized maintenance techniques, test equipment, or expertise. The recommended overhaul periods and necessary cross references to the Airworthiness Limitations section of the manual must also be included. In addition, the applicant must include an inspection program that includes the frequency and extent of the inspections necessary to provide for the continued airworthiness of the <del>UAS rotorcraft</del>.</p> <p>(2) Troubleshooting information describing problem malfunctions, how to recognize those malfunctions, and the remedial action for those malfunctions.</p> <p>(3) Information describing the order and method of removing and replacing products and parts with any necessary precautions to be taken.</p>	
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A§27.4 Airworthiness Limitations section	As is	The Instructions for Continued Airworthiness must contain a section, titled Airworthiness Limitations that is segregated and clearly distinguishable from the rest of the document. This section must set forth each mandatory replacement time, structural inspection interval, and related structural inspection procedure required for type certification. If the Instructions for Continued Airworthiness consist of multiple documents, the section required by this paragraph must be included in the principal manual. This section must contain a legible statement in a prominent location that reads: “The Airworthiness Limitations section is FAA approved and specifies inspections and other maintenance required under §43.16 and 91.403 of the Federal Aviation Regulations unless an alternative program has been FAA approved.”	Rationale: The same basic requirement to specify information on airworthiness limitations applies to an unmanned rotorcraft.
Appendix B Airworthiness Criteria for Helicopter Instrument Flight	Excluded	<p>Summary: This appendix specifies the design and installation requirements for operation under instrument flight rules.</p> <p>Rationale: Out of ConOps scope.</p>	
Appendix C – Criteria for Category A	Excluded	<p>Summary: This Appendix specifies paragraphs under Part 29 that must be met in addition to Part 27 for Category A operation (for multi-engine rotorcraft)</p> <p>Rationale: Out of vehicle scope.</p>	

Appendix D HIRF Environments and Equipment HIRF Test Levels	Modified	<p>This appendix specifies the HIRF environments and equipment HIRF test levels for electrical and electronic systems under §27.1317. The field strength values for the HIRF environments and laboratory equipment HIRF test levels <i>must be established (TBD)</i>.<del>are expressed in root-mean square units measured during the peak of the modulation cycle.</del></p> <p>(a) HIRF environment I is specified in the following table:</p> <p>Table I. HIRF Environment I</p> <table><tr><th rowspan="2">Frequency</th><th colspan="2">Field strength (volts/meter)</th></tr><tr><th>Peak</th><th>Average</th></tr><tr><td>10 kHz-2 MHz</td><td>50</td><td>50</td></tr><tr><td>2 MHz-30 MHz</td><td>100</td><td>100</td></tr><tr><td>30 MHz-100 MHz</td><td>50</td><td>50</td></tr><tr><td>100 MHz-400 MHz</td><td>100</td><td>100</td></tr><tr><td>400 MHz-700 MHz</td><td>700</td><td>50</td></tr><tr><td>700 MHz-1 GHz</td><td>700</td><td>100</td></tr><tr><td>1 GHz-2 GHz</td><td>2,000</td><td>200</td></tr><tr><td>2 GHz-6 GHz</td><td>3,000</td><td>200</td></tr><tr><td>6 GHz-8 GHz</td><td>1,000</td><td>200</td></tr><tr><td>8 GHz-12 GHz</td><td>3,000</td><td>300</td></tr><tr><td>12 GHz-18 GHz</td><td>2,000</td><td>200</td></tr><tr><td>18 GHz-40 GHz</td><td>600</td><td>200</td></tr></table> <p>In this table, the higher field strength applies at the frequency band edges.</p> <p>(b) HIRF environment II is specified in the following table:</p> <p>Table II. HIRF Environment II</p> <table><tr><th rowspan="2">Frequency</th><th colspan="2">Field strength (volts/meter)</th></tr><tr><th>Peak</th><th>Average</th></tr><tr><td>10 kHz-500 kHz</td><td>20</td><td>20</td></tr><tr><td>500 kHz-2 MHz</td><td>30</td><td>30</td></tr><tr><td>2 MHz-30 MHz</td><td>100</td><td>100</td></tr></table>	Frequency	Field strength (volts/meter)		Peak	Average	10 kHz-2 MHz	50	50	2 MHz-30 MHz	100	100	30 MHz-100 MHz	50	50	100 MHz-400 MHz	100	100	400 MHz-700 MHz	700	50	700 MHz-1 GHz	700	100	1 GHz-2 GHz	2,000	200	2 GHz-6 GHz	3,000	200	6 GHz-8 GHz	1,000	200	8 GHz-12 GHz	3,000	300	12 GHz-18 GHz	2,000	200	18 GHz-40 GHz	600	200	Frequency	Field strength (volts/meter)		Peak	Average	10 kHz-500 kHz	20	20	500 kHz-2 MHz	30	30	2 MHz-30 MHz	100	100	<p>Rationale: Specific requirements for HIRF environments and equipment HIRF test levels were deleted and a placeholder inserted indicating that HIRF environments and equipment HIRF test levels need to be established for UAS. There is insufficient evidence, to date, to establish whether HIRF requirements specified in Part 27, Appendix D are applicable <i>as is</i> to UAS and to their intended operational environments. It is possible, given that agricultural UAS are expected to fly slow and close to the surface that HIRF environments different from those for Part 27 rotorcraft may be encountered.</p>
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		<p>susceptibility tests with continuous wave (CW) and 1 kHz square wave modulation with 90 percent depth or greater. The conducted susceptibility current must start at a minimum of 0.6 milliamperes (mA) at 10 kHz, increasing 20 decibels (dB) per frequency decade to a minimum of 30 mA at 500 kHz.</p> <p>(2) From 500 kHz to 40 MHz, the conducted susceptibility current must be at least 30 mA.</p> <p>(3) From 40 MHz to 400 MHz, use conducted susceptibility tests, starting at a minimum of 30 mA at 40 MHz, decreasing 20 dB per frequency decade to a minimum of 3 mA at 400 MHz.</p> <p>(4) From 100 MHz to 400 MHz, use radiated susceptibility tests at a minimum of 20 volts per meter (V/m) peak with CW and 1 kHz square wave modulation with 90 percent depth or greater.</p> <p>(5) From 400 MHz to 8 gigahertz (GHz), use radiated susceptibility tests at a minimum of 150 V/m peak with pulse modulation of 4 percent duty cycle with a 1 kHz pulse repetition frequency. This signal must be switched on and off at a rate of 1 Hz with a duty cycle of 50 percent.</p> <p>(e) <i>Equipment HIRF Test Level 2.</i> Equipment HIRF test level 2 is HIRF environment II in table II of this appendix reduced by acceptable aircraft transfer function and attenuation curves. Testing must cover the frequency band of 10 kHz to 8 GHz.</p> <p>(f) <i>Equipment HIRF Test Level 3.</i> (1) From 10 kHz to 400 MHz, use conducted susceptibility tests, starting at a minimum of 0.15 mA at 10 kHz, increasing 20 dB per frequency decade to a minimum of 7.5 mA at 500 kHz.</p> <p>(2) From 500 kHz to 40 MHz, use conducted susceptibility tests at a minimum of 7.5 mA.</p> <p>(3) From 40 MHz to 400 MHz, use conducted susceptibility tests, starting at a minimum of 7.5 mA at 40 MHz, decreasing 20 dB per frequency decade to a minimum of 0.75 mA at 400 MHz.</p> <p>(4) From 100 MHz to 8 GHz, use radiated susceptibility tests at a minimum of 5 V/m.</p>	
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14. ABSTRACT  As part of NASA's Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project, NASA is conducting research to investigate airworthiness requirements for UAS performing low-risk commercial operations. The goal of the research is to help fill the void in standards needed to certify UAS to operate routinely and safely in the NAS. Specifically, a case study was conducted to suggest airworthiness requirements for a midsize unmanned rotorcraft performing precision agricultural spraying operations over uninhabited fields. The study considered operations in visual line-of-sight, beyond line-of-sight, and in reduced visibility conditions. This report contains research prototypes of some of the documentation needed to support airworthiness certification, including a proposed (or mock) type certification basis with design and performance criteria for the unmanned rotorcraft, corresponding rationale, a concept of operations, and a hazard list.						
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